PROCEEDINGS

THE INSTITUTION OF CIVIL ENGINEERS

PART II
OCTOBER 1953

MARITIME AND WATERWAYS ENGINEERING DIVISION MEETING

10 March, 1953

Lieutenant-Colonel R. H. Edwards, Member, Chairman of the Division, in the Chair.

The following Paper was presented for discussion and, on the motion of the Chairman, the thanks of the Division were accorded to the Author.

Maritime Paper No. 23

"Port of London Authority Engineering Works, 1952"

by

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SYNOPSIS

Engineering work in the Port of London has been recorded from time to time and this Paper deals with the repairs carried out since the end of the war in 1945. The organization of the Chief Engineer's Department is described generally and comments are made on the current cost of maintaining an undertaking and of financing replacements.

The civil engineering section deals with storing timber, increasing the height of transit sheds without dismantling, and general requirements for planning areas in docks, with examples of buildings which have been erected in accordance with these requirements. The use of prestressed concrete for transit shed construction and aluminium for roofing is reported, with remarks on difficulties and costs.

The mechanical engineering section describes the use of synthetic resin adhesive for repairing greenheart penstock-paddles. The quay crane replacement programme proceeding in London is mentioned in some detail, with the reasons for adopting certain sizes. Wall and roof cranes are compared, the numbers of mobile cranes and trucks in use are recorded and some notes on the experience gained in the use of fork-lift trucks are provided.

The marine engineering section provides an account of the lubrication of a dredger ladder and the savings which resulted, and gives the leading dimensions of the new tugs, the reasons for adopting two-stroke-cycle diesel main engines, and the results of a trial with a Kort nozzle.

Introduction

The Port of London is as old as the city which it serves, but the Port of London Authority is a still young and vigorous body created by Act of Parliament in 1908. A selection of books dealing with the history of the Port and Papers written for this and other Institutions is given in the Appendix. The Author proposes to deal only with engineering work which has been done since 1945 to restore the facilities which were lost by enemy action and to provide new services to meet trade requirements.

In 1938, the total tonnage of goods imported, exported, or trans-shipped within the Port of London Authority's docks was 16½ million tons. In 1952 the tonnage had once again risen to this figure. At the end of the war 30 per cent of the warehouses and 25 per cent of the transit-shed capacity had been destroyed and the war damage compensation paid to the Authority was a little more than 13 million pounds. Because the supply of labour and materials has been restricted in one way or another since the end of the war, many acres of the docks are still devastated, but the figures for trade, which have been quoted above, indicate that the work which has been done has been turned to good account.

For various domestic reasons the engineering staff of the Authority was unusually small in 1939 and it was further depleted during the war, so that to a very large extent a new organization had to be developed to carry out the post-war policy of the Board. This was, first, that arrears of maintenance should be undertaken by the Chief Engineer to the full capacity of his organization without financial limit; secondly, that partially damaged buildings should be repaired; and thirdly, that restorations involving extensive rebuilding should be undertaken. This policy aimed at getting the highest production from the assets left to the Port before staff and resources were allocated to the large schemes of rebuilding and development, which naturally involved considerable investigation—it being seldom possible to meet the current needs of trade by restoring to the original plans.

This is broadly the stage which has been reached after 7 years and the Author hopes to cover the comparatively small works which have been carried out so that the larger developments contemplated can provide subjects for separate Papers in their turn and will be seen against their proper background.

Engineering Organization

Where engineering problems of magnitude arise, no authority can afford to have anything but the best engineers and when this policy is accepted engineers are costly. The organization must therefore be designed to confine its work to professional engineering; for information and work on such things as contract legalities, accountancy, costing, stores purchasing,

land and estate matters, etc., reliance should be placed on the appropriate departments. The Author considers that where engineers deviate from the principle of a single engineer adviser to the board and management they weaken their professional position because it is unlikely that the service rendered will have the unequivocal assurance which should be the keynote of the professional advice. It is also considered that engineers should not be used for work which can be delegated to clerical staff.

The distance between the seaward and landward limit of the Port is 68 miles, but the dock groups are confined to the 30 miles down river from the Head Office on Tower Hill. Because of the easy communication which exists between the docks and Head Office, administration and major design can be centralized at Head Office and the executive work decentralized to dock controls without misunderstanding developing at either extremity.

The Chief Engineer is the Port Authority's adviser on all civil, mechanical, electrical, and marine engineering and other technical matters. He has a deputy and a personal assistant engineer, three engineers to deal with mechanical, electrical, and design matters, with a central drawing office and clerical sections covering correspondence, contracts, finance, labour, insurance, and claims. The controls, each headed by a Divisional Engineer comprise :—

(*a*) London and St Katharine Docks.
(*b*) Surrey Commercial Docks.
(*c*) India and Millwall Docks.
(*d*) Royal Docks.
(*e*) Tilbury Docks.
(*f*) River.
(*g*) Marine.
(*h*) Drawing Office.

The dock Divisional Engineers (*a*) to (*e*) may possess civil or mechanical engineering qualifications or both. Each has an assistant engineer, mechanical, and may have an assistant engineer, civil. The assistant engineers, mechanical, are responsible for electrical maintenance. This is the general pattern but, during the present period of rebuilding and re-equipment, some additional assistant engineers are employed to enable the professional ability of the Divisional Engineers to be used to the widest extent. The Divisional Engineer, River, is concerned with piers, banks, dredging, and conservancy, and has no assistant. The Divisional Engineer, Marine, maintains the Authority's dredging and salvage craft, tugs, and boats and has an assistant. The engineers total nine Divisional and thirteen Assistants. Divisional Engineers have an appropriate number of clerks of works, inspectors of mechanical, electrical, and marine work and, in certain docks, refrigeration and grain elevator inspectors, together with draughtsmen and small clerical staffs.

Generally maintenance work is done by maintenance contractors and

new construction under contracts secured by competitive tenders, but since the war a direct labour force with its contingent buildings and equipment is being organized for the day-to-day maintenance of small mechanical plant and to deal with items which would otherwise form daywork payments under the building maintenance contract. A system has been developed with the Authority's Chief Accountant, using Hollerith machines, which provides the Divisional Engineers with statements of expenditure on direct labour and material one week after the week in which the work is done. After the engineering decisions have been made the mechanical maintenance work is done by a contract on a cost-plus basis checked by audit, which necessitates supervision of method and quality of the work, while for civil engineering and building maintenance the contract is paid by measurement on a schedule of prices, which largely necessitates only supervision of the quality of work. The joint quantity surveyors for the Authority and the civil engineering maintenance contractors are Messrs George Corderoy & Co., and it may be mentioned that the arrangement with the contractors to employ a firm of quantity surveyors jointly results in some saving in time, cost, and correspondence.

The average numbers employed on maintenance and capital works are :—

(*a*) Direct labour employed on operation and maintenance, civil, mechanical, and electrical	900
(*b*) Contract labour employed on mechanical and electrical maintenance	1,100
(*c*) Contract labour employed on mechanical and electrical contracts	50
(*d*) Contract labour employed on civil engineering and building maintenance	1,000
(*e*) Contract labour employed on civil engineering contracts	350
Total . .	3,400

Before leaving the engineering organization the Author would mention that because of the shortage of experienced maritime engineers the Authority has examined the capacity for training young engineers which exists in the engineering work in progress and decided to introduce a scheme which has been developed under the rules laid down by the Institution, providing a course of up to 3 years' duration for engineers who have obtained a degree. Five places are provided under this training scheme.

Finance

The duty of a statutory authority is to provide the services defined in its statute as economically as possible and maintain and improve those services as need arises, any surplus of revenue being used to reduce the rates

charged for the services. In addition to the financial control under the Authority's Acts of Parliament, the observance of the Authority's duty is ensured by the election of a Board consisting of members representing sections of the community intimately concerned in the operations of the Authority and not merely indirectly affected by its proceedings.

Following the payment of working and establishment expenses, the cost of maintenance of the port is a prior charge on the revenue of the Authority in any year, and maintenance for this purpose has been accepted as including the renewal of plant and equipment, except so far as renewal may involve an element of betterment, when an assessment of that betterment is taken as capital expenditure.

For accounting purposes and in conformity with the grouping adopted by most other dock and harbour undertakings, the Authority's assets are divided into permanent property and renewable equipment, both of which have to be kept in repair, and the maintenance expenditure so incurred is divided for domestic purposes, as well as for simplicity of administration, into three groups.

Group I.	Ordinary Maintenance .	Day-by-day servicing and repairs undertaken on the Chief Engineer's authority.
Group II.	Periodical Maintenance	Large overhauls and sectional renewals advised as due to be undertaken by the Chief Engineer but which may be deferred for financial or operating reasons providing the charges for intensified deterioration are covered annually.
Group III.	Deferred Repairs . .	Repairs deferred during the war years and subsequently, and undertaken eventually together with any intensified deterioration which is estimated as one twentieth of the outstanding balance at each year's end.

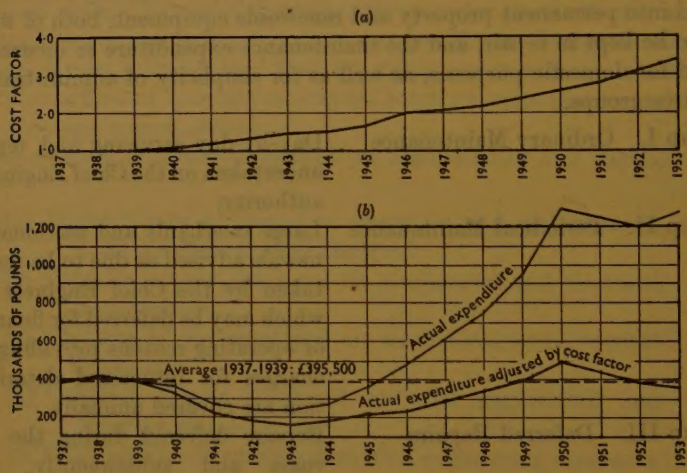
Deferred Repairs can arise only when, for some reason such as war, it is impossible to maintain the undertaking to the standard contemplated by Parliament in the Authority's Acts. The commitment should not be allowed to become an unwieldy burden on the engineering and financial resources of the Authority.

In addition to maintaining the renewable equipment, provision has to be made from revenue for replacing items in this category when they reach the end of their useful life, which may range from 5 to 70 years or more. In the past this does not appear to have been a problem, because increases in cost were compensated by expanding revenue, but to-day the rapid rise in

replacement costs compared with book values or, as they are now called, " historical values " has created financing difficulties which have been dealt with in various ways by nationalized and commercial concerns. The present method in the Port of London still adheres broadly to the principle that equipment should earn its keep, which means that the revenue must bear the cost of replacing worn-out assets in order to avoid placing a burden of capital debt on future generations.

If a concern is sufficiently large and consistent in its activities, the annual amount of replacement tends to become uniform. This is true for the Authority and the revenue is charged annually with a sum to meet this commitment. The annual charge is now calculated from the 1939 valuation

Figs 1



CIVIL AND MECHANICAL ENGINEERING EXPENDITURE

(*a*) Increase in the cost of civil and mechanical engineering maintenance, related to 1939.

(*b*) Annual expenditure on civil and mechanical engineering maintenance, actual and adjusted by cost factor.

of the assets in use, an average life of 50 years being assumed and the figure obtained adjusted for price increases since 1939 and additions made for recently purchased plant on a similar basis. The present annual provision of £350,000 is meeting current expenditure, which would seem to be the best test to apply when examining the value of any method devised for computing this annual replacement figure. Although more refined methods of calculation have been employed, their worth may be questioned if their use involves a great deal of clerical or other work.

Engineers responsible for large installations have been concerned in recent years by the mounting cost of mechanical and civil engineering work ;

Fig. 1 (*a*) shows graphically the cost factors which have been used from time to time in the Port to relate the current costs of civil and mechanical maintenance with 1939 figures. *Fig. 1* (*b*) shows the annual expenditure on civil and mechanical ordinary maintenance and the same expenditure adjusted by the appropriate cost factor. The enforced neglect during the war years and the effort made to retrieve the position are illustrated. As a check on the cost factor the labour employed on civil engineering maintenance in the Royal Group of Docks was ascertained for various years and representative figures are :—

1939	12,007 man-weeks cost	£70,572. Factor 1·00
1950	11,960 ,, ,, ,,	£191,396. Factor 2·72

The cost of the upkeep of an undertaking must be related to the proportion of old and new buildings and plant and the amount of use, and it is suggested that in the case of a port the tonnage of goods handled over the quays may be taken as a measurement of usage. The figures for London are given in Table 1. These figures show that the amount of goods handled now exceed the 1938 figure and suggest that with the steady increase over recent years the annual expenditure on the maintenance of cranes, trucks, quays, and buildings may be expected to rise apart from the increase in the cost of work.

TABLE 1.—TONNAGE OF GOODS DISCHARGED AND LOADED BY VESSELS USING THE PORT OF LONDON AUTHORITY'S ENCLOSED DOCKS

Year ending 31st March	Tonnage of goods handled within the docks			
	Imports	Exports	Transhipment (doubled figures)	Total
1938	11,464,842	2,342,801	2,699,510	16,507,153
1939	10,564,972	2,162,950	2,501,172	15,229,094
1948	9,180,867	2,422,677	1,671,462	13,275,006
1949	8,732,744	3,241,879	1,828,770	13,803,393
1950	9,081,965	3,637,989	1,946,352	14,666,306
1951	9,554,400	3,987,471	2,212,550	15,754,421
1952	10,016,537	3,976,651	2,561,960	16,555,148

The apparent stabilizing of expenditure on maintenance shown in *Fig. 1* (*b*) arises partly from increased expenditure on Deferred Repairs which, in the opinion of the Author, reduces to some extent the amount which needs to be spent on current maintenance, and partly from increased supervision by professional engineers, which has obtained more work for the same money.

The Author has been unable to find any satisfactory measure for the reasonable cost of maintaining an undertaking but has examined with

interest the financial section of the Annual Reports of the British Transport Commission. In the years 1948 and 1951 the current capital assets of the Docks Section for plant, equipment, ways, and structures are given as £72·3 million and £78·4 million respectively. The corresponding cost of annual maintenance is given as £2·6 and £3·1 million representing 3·6 and 3·95 per cent on the capital value.

An interesting comment on this question of the cost of maintenance and the expenditure necessary to reinstate an undertaking which has been neglected is provided by a passage from the " History of the Port of London " by Sir Joseph G. Broodbank. The passage, which appears on p. 352 of Volume II, was written in 1921 and refers to events which took place in 1910; it reads as follows :—

". . . There is, however, no gainsaying the general impression of the commercial public and of the members of the Authority that there were years of neglect to make up . . .

" The chief engineer accordingly examined the dock properties and premises, and he reported generally that they had not been maintained in a proper state of repair, and that to insure the efficient and safe working of the undertaking a large and immediate expenditure was absolutely necessary. The resident engineers who had been for some years in charge were instructed to prepare estimates of the cost of the repairs and renewals required in order to bring the properties into an efficient state of maintenance. The total estimated cost was £735,611. . . .

" The estimate was adopted by the Authority, but for financial reasons it was found practicable only to sanction an immediate expenditure of about £70,000 on such of the repairs as were most urgent. In following years progress was made with the works and at the opening of the war in 1914 a sum of £419,000 had been spent . . . little more than half the sum which, according to their chief engineer, was immediately necessary to " insure the efficient and safe working of the dock undertakings." It may be added that at no period of their existence have the demands upon the docks been so insistent as during the war, and yet work has been carried on without any hitch due to neglect of maintenance.

" Apart from dredging, of keeping the machinery in perfect condition, and of securing the safe manipulation of handling goods in warehouses and sheds, the question of maintenance of docks is largely one of what a board choose to spend on it. In the nature of things there is much work done at the docks in which the rough handling of goods by even a small proportion of the labour employed soon dents and damages the surface of quays and sheds, especially when the construction is of iron or timber. The employment of brick and the frequent painting of buildings and the constant renewals of surfaces will render the docks much more presentable, and if merchants and shipowners think it worth while paying it can be done. But they usually decline to be interested the moment they are asked to pay for appearances only, and it is some defence of their attitude that the

materialization of the ideals of engineers, if unchecked by commercial expediency, might easily be the ruin of the greatest port in the world."

Civil Engineering

As set out at the beginning of this Paper the policy in the period under review has been first to repair and secondly to reconstruct. Consequently the work, although commercially important, has not been remarkable from an engineering point of view.

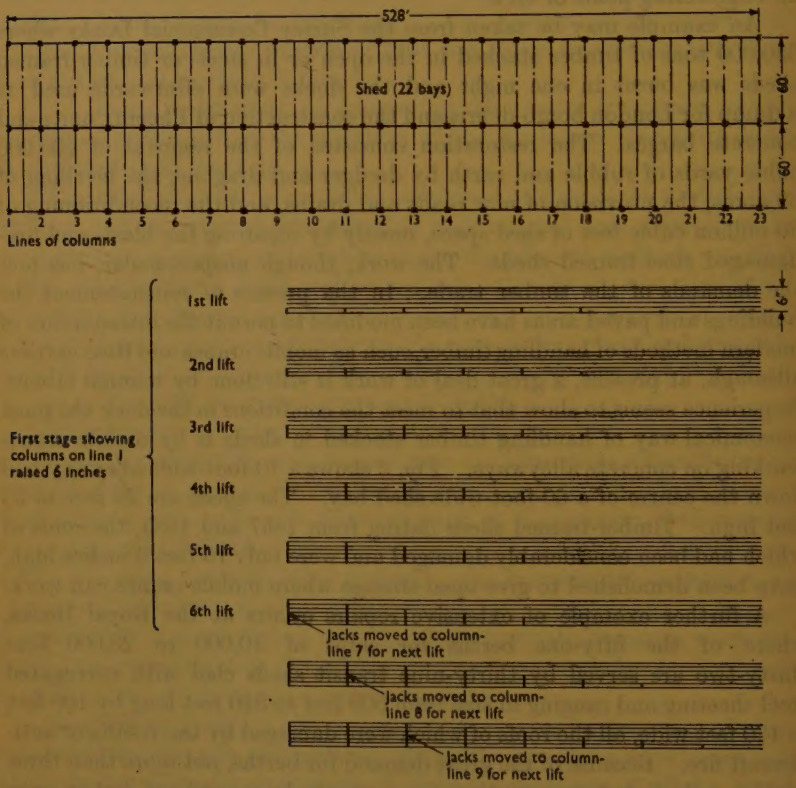
An example may be taken from the Surrey Commercial Docks where 350,000 tons of timber stacked in the open or in steel- or timber-framed sheds was burnt in one night and the docks were afterwards used as a dump for London bomb-debris and the construction of Phoenix units and concrete barges. The restoration consisted of the removal of 400,000 cubic yards of rubble and earth by dredger and dragline, the levelling of 39 acres, the provision of new roads and drains, and the reconditioning of 30 million cubic feet of shed space, mostly by repairing the blast- and fire-damaged steel-framed sheds. The work, though unspectacular, has met the demands of the timber trade. In the process of reinstatement the buildings and paved areas have been modified to permit the introduction of modern methods of handling timber, such as mobile cranes and Ross carriers although, at present, a great deal of work is still done by manual labour. Experience seems to show that to meet the conditions in the dock the most economical way of handling timber stacked in sheds is by mobile cranes working on concrete alleyways. *Fig. 2* shows a 10-foot-wide alleyway laid down the centre of a 60-foot-wide shed bay. The sheds are 26 feet to 33 feet high. Timber-framed sheds dating from 1867 and 1885, the roofs of which had been considerably damaged and were only 16 feet 6 inches high, have been demolished to give open storage where mobile cranes can work.

A further example of extensive repairs occurs at the Royal Docks, where of the fifty-one berths for ships of 10,000 to 28,000 tons thirty-two are served by thirty-nine transit sheds clad with corrugated steel sheeting and ranging in size from 300 feet to 540 feet long by 100 feet to 120 feet wide, all the roofs of which were damaged by the results of anti-aircraft fire. Because of the great demand for berths, not more than three could be released at any one time for repairs to be carried out, but in spite of this, during the post-war period twenty-three transit sheds have had the floors, walls, roofs, and doors completely overhauled. Here again, however, the engineering interest is very limited. On the south side of the King George V Dock it may be of interest to record that four sheds, 528 feet long by 120 feet wide, were raised 4 feet 6 inches in height without dismantling the sheds. The original height was 10 feet, but to enable goods to be stacked by mobile cranes a new height of 14 feet 6 inches was required. The sequence of operations in raising the sheds is shown in *Figs 3* and *4*.

The shed was prepared by the removal of all wall and roof sheeting

which required repair, the excavation of column footings and the disconnexion of foundation bolts. Eighteen screw jacks lifting 10 tons for 6 inches were used simultaneously on six rows of columns, and twenty-four columns were lifted per day by thirty men, the total lift of 4 feet 6 inches being completed in 252 lifts occupying 4 weeks. The difference in height between adjoining columns never exceeded 1 inch. When each column had been

Figs 3


528'
Shed (22 bays)
60
60
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Lines of columns
First stage showing columns on line 1 raised 6 inches
1st lift
2nd lift
3rd lift
4th lift
5th lift
6th lift
6
Jacks moved to column-line 7 for next lift
Jacks moved to column-line 8 for next lift
Jacks moved to column-line 9 for next lift

King George V Dock. Sequence of Operations in Raising Transit Shed 4 feet 6 inches

raised 4 feet 6 inches in the guides provided, a section of column was inserted and welded to the original column with splice plates.

At the time when the work was carried out, the estimated cost of providing a new shed, 528 feet by 120 feet by 14 feet 6 inches, was £48,000 for work above floor level; the cost of raising the old shed, repairing, and painting it was about £30,000, giving a saving of about £70,000 on the four sheds.

TABLE 2.—STATEMENT SHOWING ROAD AND RAIL TRAFFIC AT TILBURY DOCK FOR YEARS ENDING 31st MARCH, 1939, 1948, 1949, 1950, AND 1951

	Year ending								
	31st March, 1939	31st March, 1948		31st March, 1949		31st March, 1950		31st March, 1951	
	Tons	Tons	Increase over 1939 : per cent	Tons	Increase over 1939 : per cent	Tons	Increase over 1939 : per cent	Tons	Increase over 1939 : per cent
Imports :									
Delivered to road	9,400	79,447	745	64,235	583	78,285	733	66,876	612
Delivered to rail	74,252	97,964	32	79,608	7	80,274	8	84,213	13
	83,652	177,411	112	143,843	72	158,559	89	151,089	81
Exports :									
Received by road	17,029	78,680	362	114,953	575	132,758	680	141,960	734
Received by rail	53,524	71,990	35	83,288	56	93,093	74	108,543	102
	70,553	150,670	114	198,241	181	225,851	220	250,503	255
Total Imports and Exports :									
Road	26,429	158,127	498	179,188	578	211,043	698	208,836	690
Rail	127,776	169,954	33	162,896	28	173,367	36	192,756	51
	154,205	328,081	113	342,084	122	384,410	149	401,592	160

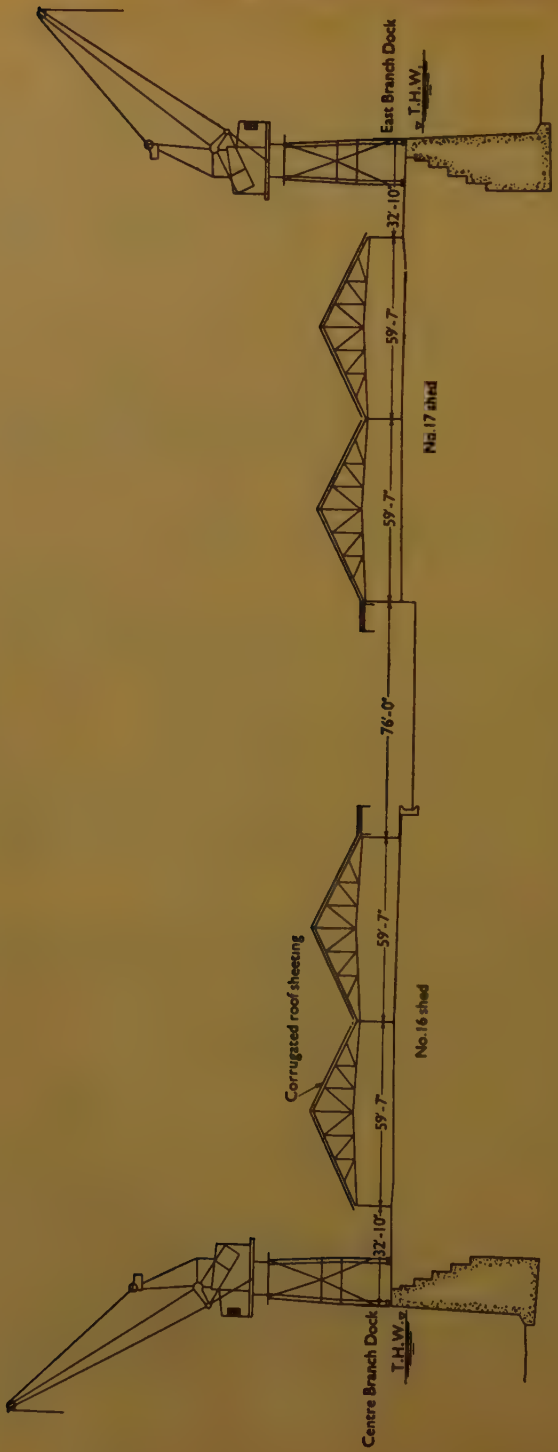
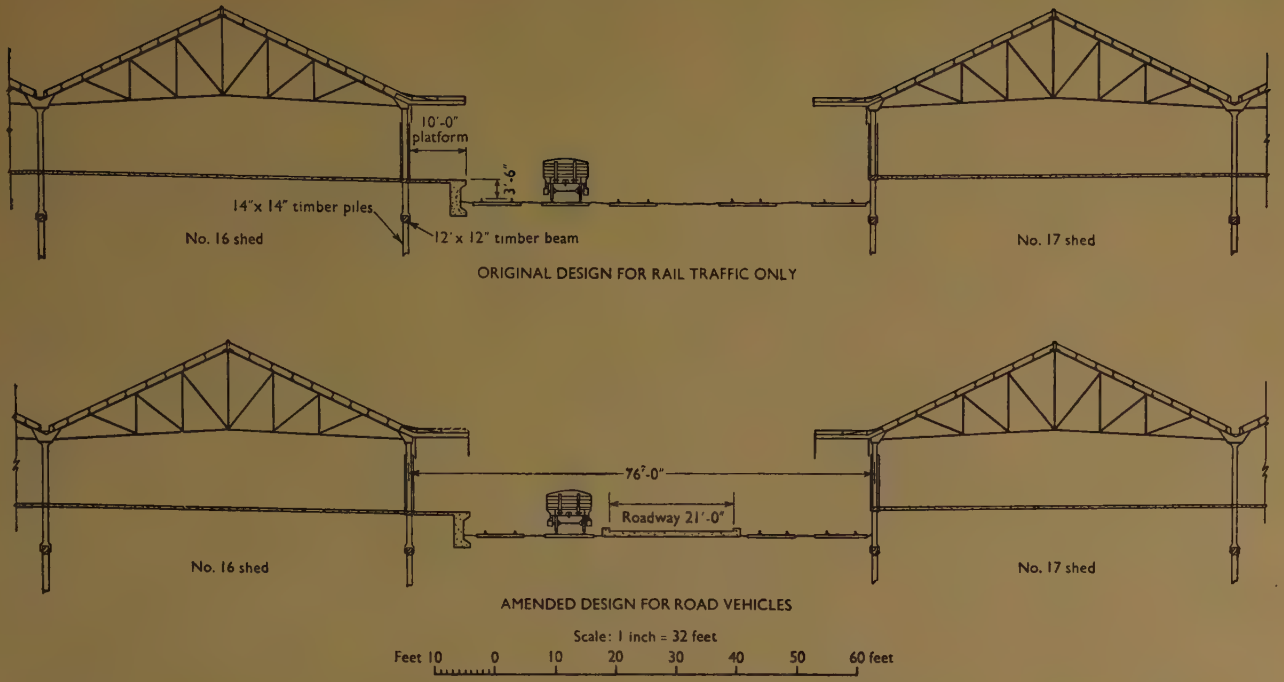

East Branch Dock
T.H.W.
32'-10"
59'-7"
59'-7"
No. 17 shed
76'-0"
59'-7"
59'-7"
No. 16 shed
Corrugated roof sheeting
32'-10"
Centre Branch Dock
T.H.W.

Fig. 5 (a)

Figs 5 (b)



TILBURY DOCK. CROSS-SECTIONS OF SPACE BETWEEN EXISTING QUAYS, SHOWING (*a*) MAIN DIMENSIONS; (*b*) ORIGINAL DESIGN FOR RAIL TRAFFIC ONLY AND AMENDED DESIGN FOR ROAD AND RAIL TRAFFIC

Before passing to sites where reconstruction has been necessary, it is proposed to mention two changes in working conditions which have influenced the new designs, namely, mechanical handling and road in place of rail transport.

The effect of mechanization, actual or anticipated, has been to reduce the number of doors in transit sheds to four per side, increase the clear head room to 20 feet, reduce the number of columns, increase the width of loading banks to 12 or 15 feet when these are still required, and increase floor loadings to 4 cwt per square foot at ground level and 2½ cwt per square foot on upper floors to enable advantage to be taken of the height to which machines will stack.

The increase in road transport is illustrated by Table 2, prepared from records kept at Tilbury, which was designed as a rail-served dock. The tonnage of goods handled by road is now approximately equal to that handled by rail. Unless there are special considerations, lay-outs need to provide for at least half the capacity of a berth being handled by road. The working space required for road vehicles has made it essential to widen quays, roads, loading banks, and shed alleyways and remove all huts and excrescences around main buildings. Offices for staff, shipping, and H.M. Customs are now being provided in sheds and warehouses on mezzanine floors with latrines, gear stores, and baggage lock-ups beneath.

The extent of the problem may be seen from an examination of the amount of vehicle parking required for the twelve berths on the south side of the Albert Dock. Assuming (*a*) that a vessel would probably stay for 14 days during which it would be discharging and loading, (*b*) that not more than three ships would be loading at maximum speed on any one day, (*c*) that for efficient loading about 1,000 tons of cargo should be collected in the transit shed for each ship and that 500 tons a day should be delivered thereafter, it is estimated that the maximum tonnage of goods which would be brought to the road in vehicles in any one day is 1,500 and, since vehicles do not always arrive fully laden, this may represent 500 vehicles. Assuming a vehicle to be 30 feet long, a double line of 500 vehicles would be 1½ mile in length, which roughly exceeds the length of the twelve berths by ½ mile and would greatly impede access to the remaining nine berths.

Figs 5 show the cross-section of the jetties at Tilbury as designed for rail traffic and as recently altered for road vehicles. Fig. 6, Plate 1, shows the cross-section which will be used for the extension at Tilbury, which is a modification of what has been envisaged as the ideal arrangement shown in Fig. 7, Plate 1, in which no restrictions have been placed on the plan by existing facilities. The large area reserved for offices, canteens, workshops, plant stores, etc., has been shown to be necessary from experience in the existing docks.

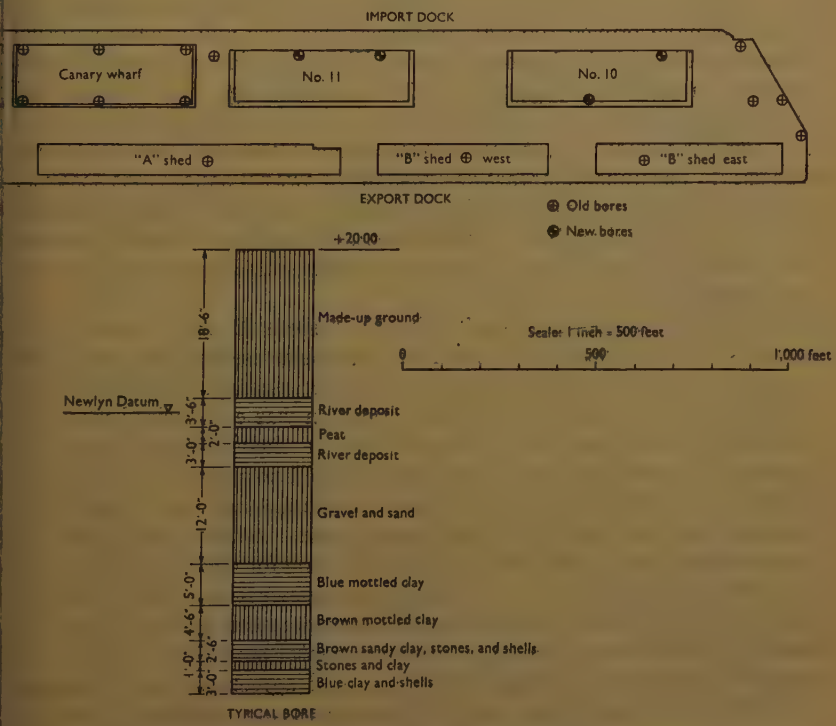
The application of the design requirements outlined may be seen in the lay-out and cross-section of the new quay and Nos 10 and 11 Sheds, West India Dock, shown on Figs 8, Plate 1. Lack of space makes it necessary to

combine transit sheds and warehousing, which otherwise would not be advocated, and the sloping floor leading to the loading bank may be superseded in later sheds if fork-lift trucks come into more general use. The quay repeats the design successfully used on the improvements to the North Side, Royal Albert Dock, described by R. R. Liddell in a Paper presented to the Institution in 1938. The simplicity of the design and the saving in shuttering are noteworthy. The cost of the Albert Dock improvement was 16*s.* 5*d.* per square foot in 1935 and the similar work completed in 1951 cost £3 1*s.* 6*d.* per square foot—an increase of 275 per cent, or a cost factor of 3·75.

The reinforced-concrete warehouses, 432 feet by 128 feet, with loading platforms on three sides represent standard practice except that expansion joints are reduced to the minimum, one only being provided in the centre of the top floor. Doubled columns are provided and the joint is made in walls and roof slab.

Bores were made as shown in *Figs 9* and test piles driven to supplement the known geological information. A penetration of 3 feet 6 inches into

Figs 9



West India Dock, Nos 10 and 11 Sheds. Record of Bores

the gravel was required to carry the load ; no cut-off exceeded 18 inches and in most cases they were considerably less. The basements of the warehouses originally occupying the site were filled with debris from the burnt-out buildings and heavy cast-iron rails were embedded in the basement floors. These obstructions were removed by grabbing pits, 13 feet deep, for each group of piles.

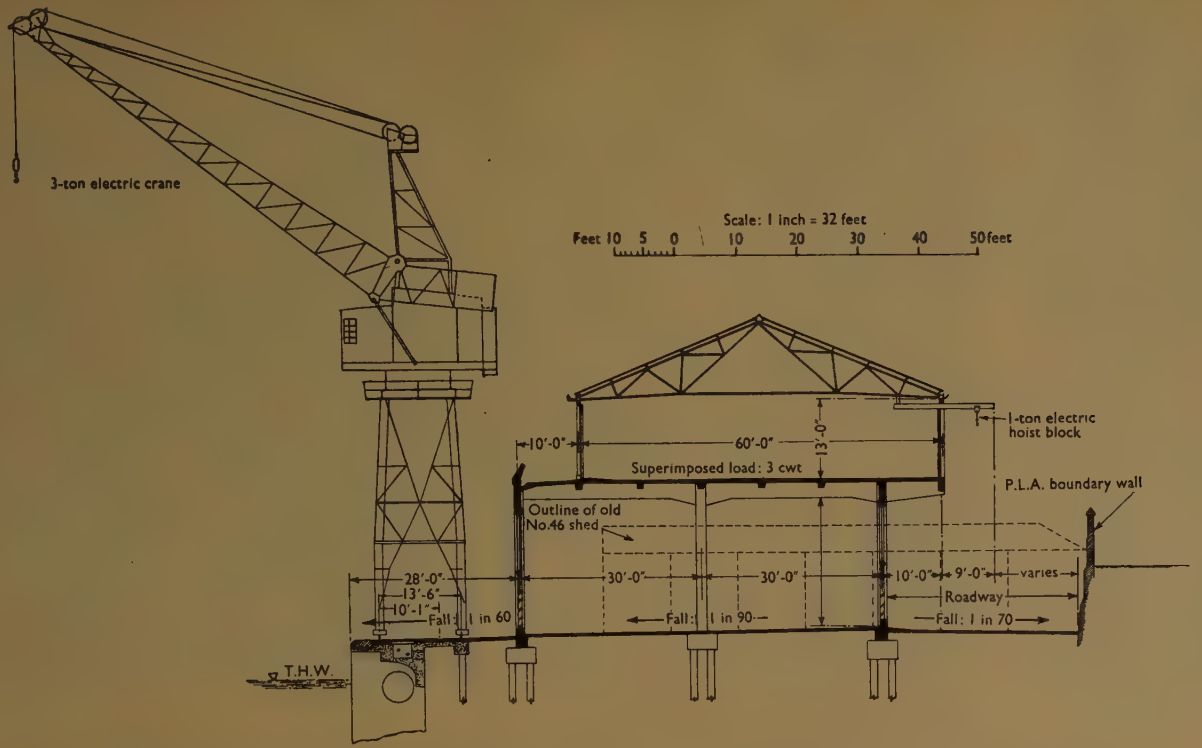
Bored piles, 30 feet long by 18 inches diameter, were used in the front row of foundations to avoid shaking the old dock wall, and were approximately double the cost of reinforced-concrete piles.

Further examples of new building are provided by Shadwell No. 27 Shed and the Eastern Dock No. 10 Warehouse, both in London Dock and shown in *Fig. 10*, Figs 11, Plate 2, and *Figs 12* and *13*. *Figs 10* and *12* each indicate the restricted access to the area before redevelopment, illustrate the design factors mentioned in the preceding paragraphs and also show that in order to give the increased space required for road vehicles and preserve the transit floor space, a two-storey design has been necessary.

At No. 10 Warehouse, two sections had been completely burned out and these were reconstructed in reinforced-concrete framework with reinforced brick panel walls, 9 inches thick, the inner skin being sand/lime bricks to improve natural lighting. The improvement in lighting was obtained but the bricks have proved too soft for transit-shed use and a more suitable material will have to be found in future. The upper floors correspond with the floors in the remaining portion of the old building. The new ground floor has been made 20 feet high by omitting the first floor and is designed for 4 cwt per square foot, which enables mobile cranes and fork-lift trucks to be used. The upper floors are designed for 1½ cwt per square foot because, since they correspond with the floors in the old section of the warehouse, the head room is only 9 feet. The new section is equipped with an electric goods lift of 50 cwt capacity, which will accommodate a loaded 1-ton electric truck.

The small transit-shed berth, No. 19 Eastern Dock, London Dock, illustrates current ideas on planning and has been used experimentally to ascertain the costs and advantages of using prestressed concrete in dock buildings. The necessity for this investigation was emphasized when the Authority invited tenders for Nos 10 and 11 sheds, West India Dock (previously described), and a contractor offered to put forward for consideration a prestressed concrete design, claiming that there would be a large saving in the quantity of steel, a 40-per-cent saving in the amount of concrete used, and about 2,000 carpenter-hours on formwork and centering, which might represent an overall saving in construction costs of 10 to 14 per cent. The proposal received serious consideration but it was decided that the project was rather large for experimental purposes and that there might be considerable delay in reaching final agreement on the design. Moreover, it did not seem certain that the saving estimated would be achieved, since the supervision and labour, being unaccustomed to pre-

Fig. 10



NEW LAY-OUT OF TWO-STOREY TRANSIT SHED NO. 27 AND QUAY AT THE NORTH SIDE OF SHADWELL BASIN

stressed concrete, might be expected to encounter a number of difficulties. The Authority approved the Chief Engineer's recommendation that an experimental design in prestressed concrete should be adopted for No. 19 berth. A strong supporting reason for this action was the need to reduce the amount of steel being used at the time when the decision was taken. The comparative estimate of quantities of steel and cost for various forms of construction for a type building was made as follows :—

Type of construction	*Weight of steel*	*Cost* £
Steel	150 tons	8,800
Precast reinforced concrete	36 tons	9,450
Prestressed concrete	3 tons	12,700

The building is shown in Figs 14, Plate 2, and the width of approximately 150 feet is spanned by two 75-foot frames. The frames are pinned at the apex and at the base of each column. Each frame consists of four sections—two rafters and two columns. All the sections are post-tensioned. The rafters are post-tensioned on the ground. The columns contain sufficient mild-steel reinforcement to withstand handling stresses but, since the joint below the shoulder is secured by compression and the cables in the columns pass through the rafter, the column cables cannot be tensioned until the rafters are seated on the columns.

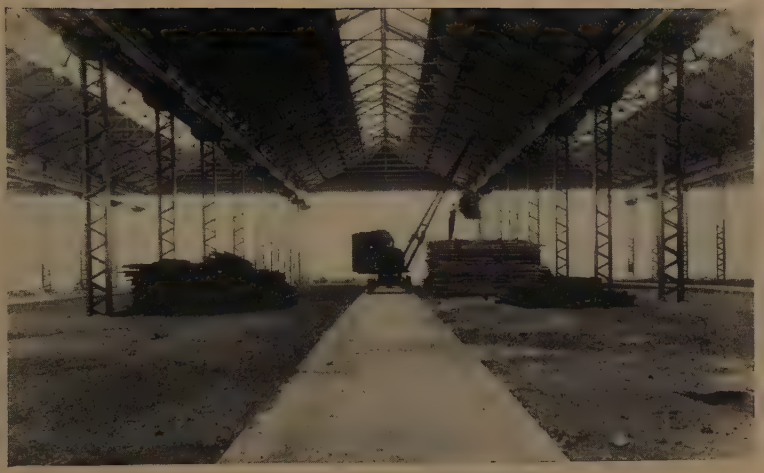
The hinge at the apex incorporates mild-steel rods and permits rotation. Any tendency for a rafter to move away from its complementary rafter is prevented by the arrangement of the ridge purlins. At the base of the column the mild-steel pin which is allowed to bend provides a rocking joint.

The rafters and columns were made on the site and were reinforced on the Freyssinet system. The rafter is reinforced by four cables, two of which are anchored by bond. The columns are reinforced by four cables.

The purlins and sheeting rails are precast and prestressed and are factory-made on the Hoyer system. The roof and side sheeting above 5 feet is of aluminium alloy and the perimeter wall up to 5 feet is built in reinforced brickwork to withstand rough usage.

It is too early at the time of writing to make an assessment of the design and construction problems, but already some points of interest have become evident. A criticism of the design is the complexity of the arrangement of cables, anchorages, and mild-steel reinforcement that is necessary in the shoulder where special reinforcement must be placed to take the high concentration of local stresses caused by the eight anchorages. Site experience shows that, in general, where cable runs depart from straight lines the accurate placing of duct tubes is tedious and expensive. It remains to be seen if this difficulty will decrease with experience. The rafter and column must be erected before they can be finally tensioned

Fig. 2



Surrey Commercial Docks. Ten-foot-wide Alleyway for handling Timber

Fig. 4

King George V Dock. Raising Transit Shed 4 feet 6 inches

Fig. 12

London Dock. Shadwell Basin. No. 27 Two-Storey Transit Shed

Fig. 13

London Dock. Eastern Dept. No. 10 Warehouse

Fig. 19

P.L.A. Tug *Plangent*. Length 85 feet between Posts.
Brake-horse-power 1,200

together. Although this procedure is necessary with the design used it makes construction difficult because of the accurate positioning required. A mobile crane and mobile towers will be used for erection.

The aggregate/cement ratio in the concrete used for the construction is about 4·0 with a water/cement ratio of about 0·3. The concrete has zero slump and is placed by vigorous vibration both on the shuttering and internally. Strengths considerably higher than 4,000 lb. per square inch at 3 days have been consistently obtained.

Because of the shortage of galvanized corrugated steel sheeting which existed in 1951, it was decided to experiment with an aluminium-sheeted roof on a transit shed at Tilbury, where the atmospheric conditions, possibly caused by cement dust, appear to be particularly injurious to galvanized sheeting, which requires patch repairs after 8 to 10 years.

The shed is 301 feet by 120 feet, the total area of the roof and canopy being 42,750 square feet. The trusses are spaced at 15-foot centres and the aluminium purlins (4-inch-by-2-inch-by-$\frac{3}{8}$-inch channel section) at 7-foot-6-inch centres. All cleats, hook bolts, rivets, washers, sag bars, ridging, gutters, and down-pipes are in aluminium. Two lines of glazing with aluminium bars are provided. The sheeting is 18 gauge with six 5-inch corrugations and is to British Standard No. 1470, aluminium-manganese alloy No. N.S.3, tempered three-quarters hard.

Overlaps and contact points with trusses are coated with zinc-chromate paint and gutter joints are made with ordinary plain putty and string. Timber anti-condensation blocks, 5 inches by 2 inches by 2 inches, shaped to fit the 5-inch corrugations, rebated $\frac{1}{4}$ inch to fit over the purlin, and drilled for the hook bolts, are provided.

The cost of the aluminium roof was £11,350, which compared with £2,800 for a similar roof carried out in steel, and the advantages hoped for from the additional expenditure are that the aluminium roof will last 15 years instead of 10 years and will not require painting every 3 years at a cost of £600. The erection was quicker because of the ease of handling and the lighting in the shed has been improved. When the work was carried out the delivery time for aluminium sheets was 5 weeks compared with 10 months for galvanized steel sheets.

Mechanical Engineering

In the equipment and operating of a port, mechanical engineering contributes a vital part which today is greater than it was when many of the permanent structures at present in use were designed, and it has become an essential part of the training of maritime engineers that they should have a high proportion of mechanical engineering experience. With the great specialization of much mechanical design it is hardly likely to be economical for the maritime engineer to design the equipment required in

detail, but he must be able to specify what is required, supervise construction, and organize efficient maintenance.

On the mechanical side, as on the civil, the first call on the resources has been maintenance, but there has been some new construction directed to increasing production from the assets remaining after the war. The Author does not intend to deal with the overhaul and replacement of fifty-six pairs of lock gates, one of the major maintenance tasks, because the data collected during this work will be offered in a separate Paper to the Institution.

One item of maintenance which may provide useful information is the repair of greenheart penstock-paddles by dressing the worn section square and building up with greenheart blocks glued in position. The blocks are 12 inches by 6 inches by $1\frac{3}{4}$ inch thick and are fixed with Aerolite 300, a cold-setting synthetic resin adhesive to B.S. 1204, 1945.

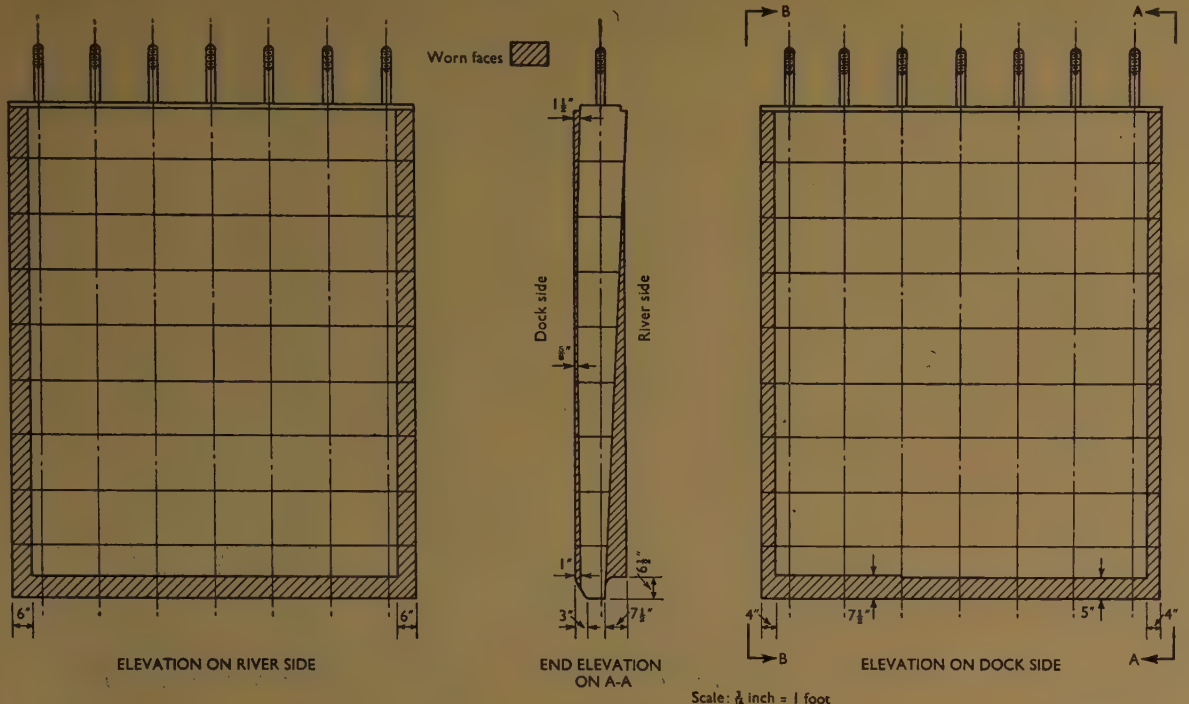
The first paddle to be repaired in this way was completed in December 1950, after some works tests had been made, and has given no trouble. New top and bottom timbers were provided as a precaution but may not have been necessary.

The work of repairing paddles varies so much that actual costs would be little help, but it seems that at least a 50-per-cent saving can be made. *Figs 15* show the wear after 33 years' use on the 13-foot-6-inch-by-11-foot greenheart paddles at Tilbury New Entrance. These paddles have been repaired by gluing.

Probably the most important and costly machines among the equipment of a modern port are the cranes, which, in London at the present time, have a replacement value of more than £5,000,000. The number required is decided by the hatches which a vessel has. Ships at deep-water berths generally have five or six hatches which can be served by four cranes on the berth and two moving in from adjoining berths, but at first-class berths in London six or more cranes are provided. It may be desirable to work two cranes in one hold if the tonnage in that hold greatly exceeds the others, because the object is to complete the unloading of all holds simultaneously.

The increase in the beam of ships and in the weight of individual packages for export has led to an increase in the outreach and the lifting capacity of cranes. A detailed analysis of a year's working of 491 quay cranes, $1\frac{1}{2}$-ton hydraulic and $1\frac{1}{2}$- to 3-ton electric, made before the war in the Port of London, indicated that the average loading of the hydraulic cranes was 20–25 cwt and of electric cranes 20–30 cwt. For 3-ton cranes maximum loads were rare. Slings, cargo nets, and boards for general cargo have changed very little, and it seems doubtful if average loads have increased. It may be said that most sets in loading and discharge can be handled by 2-ton cranes, and 3-ton cranes provide an adequate margin, except for the larger export cases for which a few 5-ton cranes are now needed. It would, however, still be uneconomical to equip a whole berth with 5-ton cranes, and the present practice is to provide one among the six.

Figs 15



ELEVATION ON RIVER SIDE

END ELEVATION ON A-A

ELEVATION ON DOCK SIDE

END ELEVATION ON B-B

Scale: $\frac{3}{4}$ inch = 1 foot

TILBURY DOCK. WEAR ON GREENHEART PADDLES FROM NEW ENTRANCE PENSTOCKS

When this practice is followed it may avoid trouble if the hiring rate for the 3- and 5-ton cranes is the same, so that the shipowner will not avoid the use of the 5-ton cranes.

The development of cranes in the Port can be judged to some extent from Table 3 which illustrates the transition from the 30-cwt non-luffing hydraulic cranes of 1913 or earlier to the 5-ton level-luffing electric cranes which are now being purchased, the former having an outreach of 35 feet and the latter 80 feet.

All quay cranes are mounted on full portals moving on rails, the gauge

TABLE 3.—CRANES IN USE IN 1952

	Radius : feet	London & St Katharine Docks	Surrey Commercial Docks	India & Millwall Docks	Royal Docks	Tilbury Docks	Total
30-cwt non-luffing hydraulic	35	12	2	15	2	—	31
30-cwt luffing hydraulic	65	30	32	60	1	16	139
30-cwt luffing electric	60	9	—	—	—	—	9
3-ton luffing electric	65	1	12	44	174	48	279
3-ton luffing electric	80	—	—	9	19	8	36
5-ton luffing electric	80	—	—	—	4	—	4
		52	46	128	200	72	498

of which is 10 feet 1½ inch for the earlier cranes and 13 feet 6 inches for those of more recent date. On some quays where it is desirable to maintain interchangeability of cranes, both gauges are available. At one of the later pre-war deep-water berths the gauge had been increased to 18 feet and in future construction this gauge is likely to be adopted. The three most recent contracts (placed in 1948/49) provide for eighty-seven 3-ton and twenty-five 5-ton cranes of the crank-operated level-luffing full-portal type, which have been proved to be trouble-free and economical in maintenance.

The sizes and capacities of these cranes are shown in Table 4.

The following are brief specifications of the cranes listed in Table 4.

3-ton cranes

Hoist . . . . . 3 tons at 240 ft per min. with 63 H.P. motor; 1½ tons at 300 ft per min.

Slew . . . . . 3 tons at 1¼ rev. per min. with 10 H.P. motor.
Luff . . . . . 3 tons at 120 ft per min. with 7 H.P. motor.
Travel . . . . 85 ft per min. with two 10 H.P. motors.

5-ton cranes

Hoist . . . . . 5 tons at 200 ft per min. with 90 H.P. motor; 2½ tons at 250 ft per min.; 1½ tons at 330 ft per min.
Slew . . . . . 5 tons at 1¼ rev. per min. with 15 H.P. motor.
Luff . . . . . 5 tons at 60 ft per min. with 10 H.P. motor.
Travel . . . . 60 ft per min. with two 10 H.P. motors.

TABLE 4

Load : tons	Radius : feet	Gauge : feet	Gauge : inches	Truck	Weight : tons
3	65	13	6	4 single wheels	74
3	80	13	6	4 double wheels	97
5	80	13	6	4 triple wheels	126

Crank luffing has the advantage that no ropes are used for holding the jib, which is balanced at all radii. The motion of the jib is harmonic, the speed being at a maximum at the middle of the range and decreasing gradually to zero at maximum and minimum outreach. If the luff motor is not switched off the jib continues to luff in and out and no limit switches are necessary. The installation of two travel motors has done away with the previous complication of shafts, bearings, and bevels. All sheaves are mounted on roller bearings.

Recent cranes are equipped with the " UNR "-type master control relay. The relay is operative on the two motions of hoist and luff, and governs the sequence and timing of the multi-notch rheostatic control of the D.C. motor contactors. At some quays it has been found necessary to short out the relay on " Stop " and notches 1 and 2 in both directions, to provide the drivers with emergency control.

The relay is pilot-motor driven and the fastest safe handling speeds are automatically selected throughout the range of crane loadings, and power is supplied to the motors smoothly at a predetermined rate which is unaffected by bad driving.

The quay cranes deliver goods from ships or barges to quays for transit sheds or to warehouse floors. After storage, the goods may return to the quay side or move forward to rail or road vehicles. The openings in the warehouse walls are equipped with flaps which can be lowered to form loading platforms protruding 2–3 feet. Over the years goods have been transferred from these to the vehicles below by various appliances, commencing with hand-operated catheads and jiggers, which later developed

into fixed-radius wall cranes, then luffing wall cranes, and now travelling level-luffing roof cranes.

Wall cranes have been replaced when damaged warehouses were repaired, an example being No. 10 warehouse (*Figs 11* and *13*), where three luffing wall cranes, lifting 1 ton at 120 feet per minute and having an outreach ranging from 10 feet to 25 feet, have been installed.

It seems possible that wall cranes may have reached the limit of their development, because of the difficulty of providing the driver with a good view for controlling operations. The main trouble is to obtain a sight of the hook in its lowest position at minimum radius. If the crane is designed to serve two tiers of openings and the top one on each side is above the level of the wall fixings of the crane, suitable positions for the operating cabins are restricted. Remote controls may be developed but seem likely to be expensive. The driver should be specially considered and all controls should be operated with a very small effort of, say, 5–7 pounds.

Roof cranes have been introduced for new warehouses such as Nos 10 and 11, West India Dock (Figs 8, Plate 1), because they are more flexible in operation and the driver has better control. The cranes are made to the same design as the quay cranes, being portable and having crank-operated level-luffing jibs. The performance has been specified as follows :—

Hoisting max. load . . .	1½ ton at 100 f.p.m., motor 12½ H.P. at 500 r.p.m.
Slewing	1½ ton at 1 r.p.m., motor 3 H.P. at 500 r.p.m.
Luffing	1½ ton at 66 f.p.m., motor 3 H.P. at 500 r.p.m.
Travelling	1½ ton at 50 f.p.m., two motors 3 H.P. at 500 r.p.m.
Max. radius	30 feet
Min. radius	12 feet 6 inches
Rail gauge	17 feet 6 inches
Total weight	33¼ tons on four double-flange wheels

In order to give the driver a good view of the load when close to the wall, dual control cabins, one on either side of the jib, are provided.

The cost of the 1-ton wall crane described is £3,390 (1952) and since the crane anchorages were designed as part of the building, their extra cost was negligible. The cost of the 1½-ton roof crane is £6,600 (1952) and the cost of the track and building work about £2,000 per shed. Four wall cranes would have been needed in place of two roof cranes.

Between receiving and forwarding goods a number of operations may be required and the plant which is now generally used is the mobile crane and battery-operated 1- or 2-ton truck. The Authority owns about 130 of the former and 160 of the latter. The cranes unload and stack or make

up palletized sets for fork-lift trucks and the mobile trucks distribute over transit sheds or may be taken in lifts to the upper floors of warehouses.

Concerning the much discussed fork-lift truck with its attendant packaging and labour problems, if packing could be revolutionized and palletization generally introduced, the future of the appliance would be assured, but at the present time its chief claim to fame is that it is the latest idea. Those who are contemplating its introduction will be interested to know that a fork-lift truck, lifting 4,000 pounds at 27 inches, costs about £1,800 and requires 300 to 500 pallets at £6 each for operation. After considerable investigation into the design of pallets the cost of maintenance still remains at about £3 per year per pallet.

Mobile cranes are required for unloading the goods when received and setting them on pallets on which they are stacked in the transit shed. The cost of equipping one shed for fork-lift-truck operation has been about £30,000.

After a period of experiment with the machines and the labour, it has been possible to reduce the number of men required for loading a ship from 100 to 40 but the pay of the men has increased. Allowing for the amortization of the capital cost of the equipment, the maintenance and fuel costs, and the increased wages, there is so far no reduction in the total cost of handling a ton of exports.

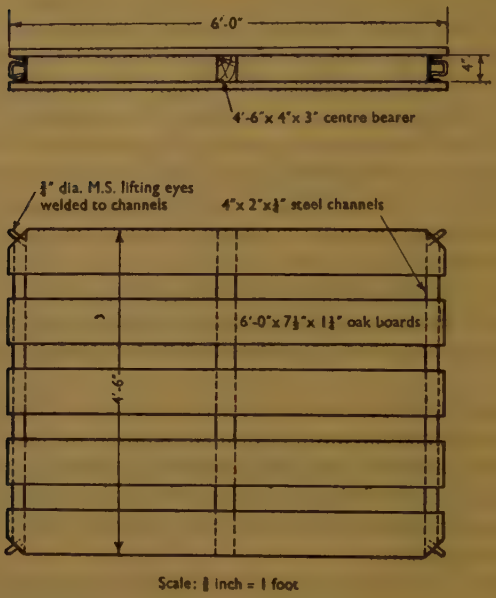
In addition to saving manpower, on the credit side may be placed less rough handling, reduction in pilferage, and as much as 20-per-cent saving in the time required to load the ship from the quay.

While this may sound very attractive it has to be realized that a great deal of the advantage offered by the fork-lift truck depends on co-operation from manufacturers in packing, labour in willingness to introduce new methods, ship owners in adopting new schedules, etc., and unless this co-operation can be secured the introduction of an expensive means of more rapid handling at one point in the process may result in an increase in the cost of transport which the consumer ultimately pays.

The design of a pallet which has been developed in the port is shown in *Figs 16*, which illustrates the lugs at the corners to enable the pallet to be used as a cargo board for slinging the goods from the quay to the hold of the ship. The possibility of lightening or strengthening these pallets by using aluminium has been considered, but the price was uneconomical.

The fork-lift trucks first used by the port were diesel driven but having regard to the experience with mobile trucks, battery-operated machines are being purchased. It is expected that these will be more economical to maintain. These machines are normally used by men working on piece work and therefore receive hard use. The two-speed reversing gear-box and clutch in earlier models now tend to be replaced by fluid couplings or electrical transmission to reduce the wear and tear of repeated stops and starts. The electrically operated truck, having less initial torque, does not place such a heavy strain on the transmission. Electric motors are cheaper

Figs 16


6'-0"
4'-6"x 4"x 3" centre bearer
¾" dia. M.S. lifting eyes welded to channels
4"x 2"x¼" steel channels
6'-0"x 7½"x 1½" oak boards
4'-6"
Scale: ½ inch = 1 foot

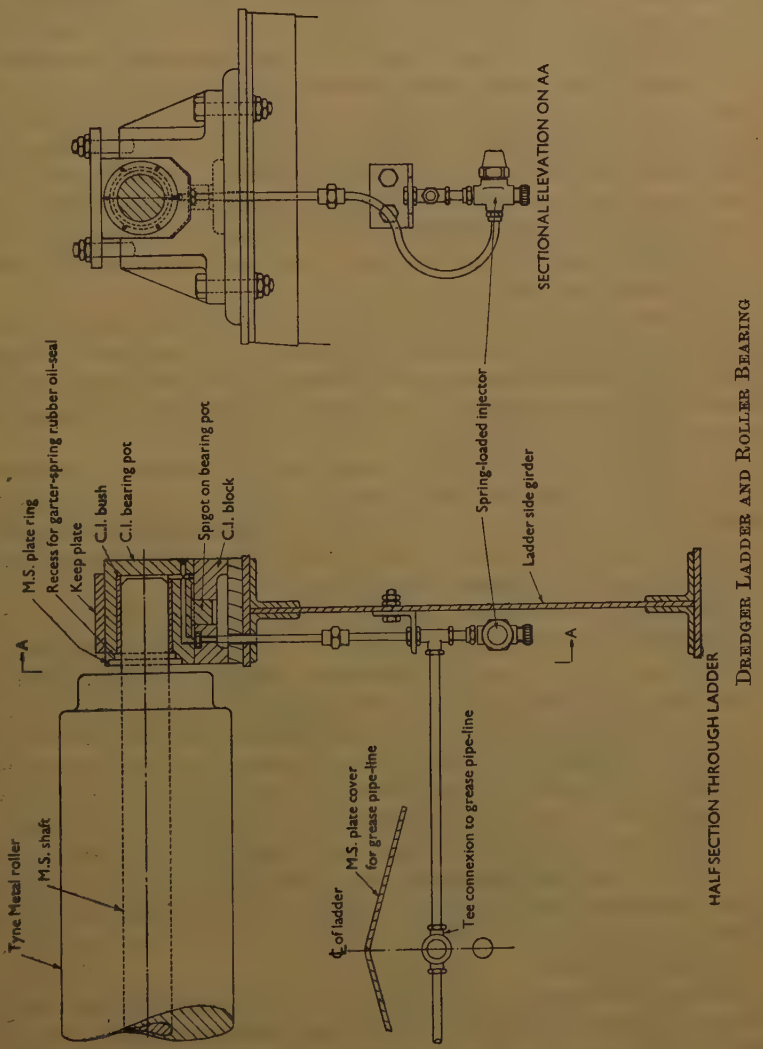
West India Docks. Fork-Lift Truck Pallet and Cargo Boards

to maintain than diesel engines. The fork-lift truck, being of compact construction to give a wheel base as short as possible, has become notorious for inaccessible components, but many manufacturers are now improving their products by mounting motors, pumps, etc., on hinged doors and connecting them with flexible pipes and drives. In this respect the battery-operated truck has an advantage in having the minimum of moving parts. The driver who is hampered by the load which he is carrying requires good visibility all round and overhead, and the guards and canopies which are being devised for these trucks as safety precautions may, in fact, have the opposite effect by obstructing the driver's vision.

Marine Engineering

The Authority's marine engineering is concerned with the purchase and maintenance of dredgers, salvage craft, tugs, harbour service launches, and boats, and since the war a considerable programme of repairs and renewals has been carried out. It is proposed to deal only with two items which may be of general interest, the first covering an experiment in dredger-ladder lubrication, undertaken to improve overall efficiency and reduce maintenance costs, and the second covering the introduction of diesel-driven tugs for berthing large vessels in the impounded docks.

The dredger selected is an open-bow-well gear-driven bucket dredger with a bucket capacity of 14 cubic feet, built in 1924 and used until this



Figs 17

overhaul on ballast dredging in the lower estuary. The ladder had to be removed for the renewal of the suspension shaft and this permitted easy access to the ladder roller bearings and bottom tumbler.

The ladder rollers had hitherto revolved on fixed shafts without any lubricant other than the water in which the vessel dredged. The bottom tumbler also revolved on a fixed shaft and received intermittent lubrication by means of a manually operated screw-down grease-gun, which could be applied only when the ladder was in the raised position. Wear on top and bottom tumbler flats, bottom tumbler shaft, ladder rollers and shafts, bucket backs, links, pins, and bushes had been both heavy and costly.

In place of the ladder roller revolving on a fixed shaft, Tyne Metal rollers with cast-in mild-steel shafts running in stub-axle bearings were introduced. The bearings are carried in flat-sided and flat-bottomed cast-iron blocks, the bottom flat being provided with a centrally cast hole to receive a spigot cast on the bearing bottom, through which the ladder-roller side-thrust is transmitted. The bearing was designed in the form of a flat-sided cast-iron pot secured by a simple flat-plate keep and fitted with a renewable cast-iron bush. (See *Figs 17.*)

The bearing is sealed on the outside by a garter-spring vulcanized-rubber oil-seal recessed into the bearing and secured by a flat steel plate ring. Grease is fed to the bearing at the bottom of the pot through a spring-loaded injector screwed into one side, which solidly packs the bearing until grease exudes past the oil seal.

The forced grease feed to the bottom tumbler is carried to each end of the shaft, where axial and radial holes convey grease to the bearing surfaces. The manganese-steel tumbler has a cast-iron bearing bush and the flanges are fitted with spring-loaded sand-excluding rings, past which the grease under pressure slowly exudes. (See *Figs 18.*)

Two electric-motor-driven grease pumps, working at 1,200 lb. per square inch pressure, are located on the superstructure platform. One feeds the bottom tumbler and one the ladder roller bearings, of which there are thirty-two. The two pipe-lines are run down the inside of the ladder ; one tee'd to each ladder roller bearing and the other tee'd at the bottom to each side of the tumbler shaft. The former, by means of a time switch, is set to start and inject the contents of an injector to each bearing every 12 minutes. The latter is a continuous-running pump with a low gear-ratio.

The dredger was recently taken out of service for observation after working on double shift at depths ranging from 28 to 45 feet for 40 weeks. The bottom tumbler was not disturbed, since the total wear on shaft and bush was found to be only $\frac{1}{16}$ inch, which proved the bearing to be efficiently lubricated.

Several of the ladder roller shafts were removed for examination of journals, bushes, and seals. It was found that the seals had effectively excluded water and mud, and grease on the surfaces was found to be clean and uncontaminated. Wear was found to be of the order of 0·030 inch on the shaft and 0·060 inch in the bush. It was considered to be remarkably low in the light of the working conditions.

The lubrication of these parts had so reduced friction that wear on the

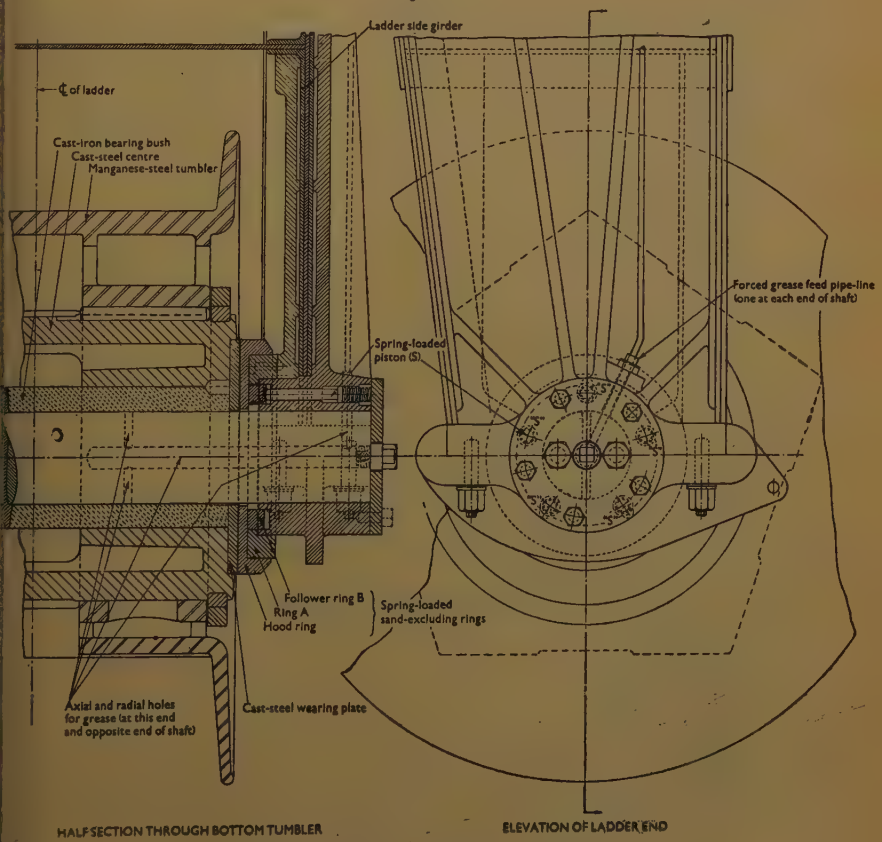
bucket-chain components was found to be practicably negligible, and is given as ollows :—

Top tumbler flats canting edges	nil
Bottom ,, ,, ,, ...	nil
Wearing surfaces of ladder rollers . . .	nil
Backs of bucket links	nil
Bucket pins	$\frac{1}{16}$ inch
Bucket and link bushes	$\frac{1}{16}$ inch

The dredger's overall efficiency was greatly improved, and the performance for the period of 40 weeks is tabulated as follows :—

Average weekly tonnage of Thames mud dredged	18,170 tons
Bucket speed	19 per min.

Figs 18


Ladder side girder
℄ of ladder
Cast-iron bearing bush
Cast-steel centre
Manganese-steel tumbler
Forced grease feed pipe-line (one at each end of shaft)
Spring-loaded piston (S)
Follower ring B
Ring A
Hood ring
Spring-loaded sand-excluding rings
Axial and radial holes for grease (at this end and opposite end of shaft)
Cast-steel wearing plate
HALF SECTION THROUGH BOTTOM TUMBLER
ELEVATION OF LADDER END

DREDGER BOTTOM TUMBLER BEARING

Fresh water boiler feed used	10·5 tons per week
Coal consumption for all purposes	18 tons per week
Grease used on the system	35 lb. per week

Prior to the fitting of forced lubrication, the dredger had worked solely on the dredging of Thames ballast, and therefore direct comparison figures for mud dredging cannot be given. An abstract from records kept whilst the vessel was a ballast dredger is set out below :—

Average weekly tonnage of Thames ballast dredged	5,500 tons
Bucket speed	17 per min.
Fresh water boiler feed used	14·5 tons per week
Coal consumption for all purposes	20 tons per week
Grease used for bottom tumbler only	28 lb. per week

Wear on bucket chain components was as follows :—

Top tumbler flats canting edges	$\frac{1}{4}$ to $\frac{5}{16}$ in. per year
Bottom tumbler flats canting edges	$\frac{1}{4}$ in. after 2 years
Wear on bottom tumbler shaft and bush	$1\frac{5}{16}$ in. after 2 years
Wear on ladder roller surfaces and ladder roller shafts	heavy, but no measured record available
Wear on bucket backs and bucket links	$\frac{3}{8}$ in. per year
Wear on bucket pins and bushes	$\frac{1}{4}$ in. per year

From the figures given, the considerable savings in (*a*) maintenance costs, (*b*) running costs, and (*c*) increased availability for service, which the forced lubrication of the ladder rollers and tumbler has afforded will be readily judged.

The Authority decided, on the advice of the Chief Engineer, that the tugs which had to be replaced after the war should be powered with direct-reversing diesel engines in order to improve availability and to reduce maintenance. Four twin-screw diesel tugs for mooring and towing services and three single-screw launch-type tugs for barge towing in the Authority's Docks have been delivered.

The principal dimensions of the twin-screw tugs are as follows :—

Length B.P.	85 feet
Breadth moulded	24 feet
Depth moulded	12 feet 6 inches
Draught aft	12 feet 3 inches
Total B.H.P.	1,200
Speed	10 knots
Static pull ahead	15 tons
Static pull astern	7·5 tons

Although the speed was specified, this was kept down, in order not to interfere with the design of the propeller to give the maximum static pull.

The craft are of the flush-deck type with a raked bar stem and raised stern (*Fig. 19*). The main tank capacities are :—

Oil fuel	26 tons
Fresh water	11 tons
Water ballast	39 tons

The tugs are designed with large ballast tanks so that the draught can be reduced by pumping to enable the vessel to dry-dock in a floating dock capable of lifting a vessel with a draught of 10 feet.

The main engines are two Crossley four-cylinder two-stroke-cycle engines developing 600 brake-horse-power at 250 revolutions per minute. The dead-slow speed for these engines is 80 revolutions per minute. Since the engines are direct-reversing the operator can give rapid engine movement in reply to the telegraph. Direct-reversing engines are preferred for maintenance and availability, and the points in favour are :—

(*a*) Two-stroke-cycle engines with port exhaust and scavenge obviate periodic attention to exhaust and inlet valves.
(*b*) Changing of fuel sprayers can be done in short idle periods.
(*c*) Overhauling of compressor valves is not a lengthy process and since there are two auxiliary air compressors the service can be arranged so that one compressor is always available.
(*d*) No gear-boxes are required.

Twin Crossley four-cylinder four-stroke-cycle engines, developing 65 brake-horse-power at 1,250 revolutions per minute, are alternatively clutch-coupled to a single 36-kilowatt generator. The steering gear is of the electro-hydraulic type and the tugs are equipped with salvage and fire pumps of 15,000-gallon-per-hour capacity. The twin air-compressor sets are electric-motor driven and a pulsometer-type sea-water-circulating pump is provided. An alternative lighting system is supplied by a 110-volt " Nife " battery with a 250-ampere capacity. A De Laval oil-fuel purifier is considered essential to reduce maintenance of fuel sprayers.

One of the four twin-screw tugs has been fitted with Kort propulsion nozzles and twin rudders and the remaining three arranged so that they can be readily fitted with similar equipment at any future date. The Kort-nozzle tug has a static pull of 20 tons and it is found that for a given pull the engine loading is considerably lighter than for the open-propeller tugs. The tugs have proved to have good manoeuvring qualities and the Kort-nozzle tug is exceptionally manoeuvrable because of the twin rudders.

The vessels are operating with a crew of master, engineer, and four men on a three-shift system. The training of personnel was carried out during the first 3 to 4 months' service of the first and second tugs. The vessels

are behaving well after the usual working-up troubles and the only minor adjustments which have been made are :—

(*a*) To improve the view for the master, the steel bulwarks round the wheelhouse have been replaced by rails and the size of the after wheelhouse windows has been increased.

(*b*) The telegraph, which was non-reply, has been fitted with a Klaxon horn which goes into operation if the operator moves the starting wheel in the opposite direction to that indicated by the telegraph.

(*c*) The air compressors are being increased from two 19-cubic-feet free-air delivery per minute to one 45-cubic-feet free-air delivery per minute, because the demand for air when handling vessels in the docks is unusually large and the smaller compressors were tending to be overworked.

One of the three launch-type tugs has a length of 51·3 feet, moulded breadth 13·1 feet, moulded depth 4·8 feet, and a brake-horse-power of 150. The other two tugs have the following dimensions :—

Length	41·9 feet
Breadth	12·7 feet
Depth	4·7 feet
Horse-power	90

The tugs have a flush deck, one mast, straight-raked stem, elliptical stern, and all have four watertight bulkheads. The tugs are equipped with single spring-type tow hooks and are capable of static pulls as follows :—

(*a*) 150-horse-power tug	35 cwt
(*b*) 90-horse-power tugs	23 cwt

The engines are Crossley ERL two-stroke-cycle engines, having three cylinders in the smaller tugs and five cylinders in the large tug. The tugs are of all-riveted construction and of robust design. They are giving excellent results in service, and the availability is extremely good. They have remained in service for continuous periods of as long as 12 months with three changes of fuel sprayers. The engines are of the direct-reversing type, and again, provided the air compressor is maintained in good condition, reversal of the engine can be carried out instantaneously and there is no gear-box requiring maintenance. Owing to the number of starts and stops the cylinder-starting air valves require attention about every 3 months but it has been found that these minor running repairs can be carried out during their idle periods.

The vessels have, in addition to the main engine, an auxiliary four-stroke-cycle single-cylinder engine driving an auxiliary air compressor and a general service pump, which is equipped to pump out barges and to be used as a fire pump.

The 90-horse-power tug has a crew of two and the 150-horse-power tug a crew of three.

Acknowledgements

The information in the Paper has been made available by the kindness of the Chief Engineer of the Port of London Authority, Mr. W. P. Shepherd-Barron, M.C., T.D., M.I.C.E., M.I.Mech.E., and the Author wishes to express his sincere thanks for this favour and to the many members of the staff who have assisted with information, drawings, views, criticisms, and typing.

The Paper is accompanied by four photographs and sixteen sheets of drawings, from which the half-tone page plates, folding Plates 1 and 2, and the Figures in the text have been prepared, and by the following Appendix.

Appendix

Selection of References

books

(in alphabetical order of Authors' surnames)

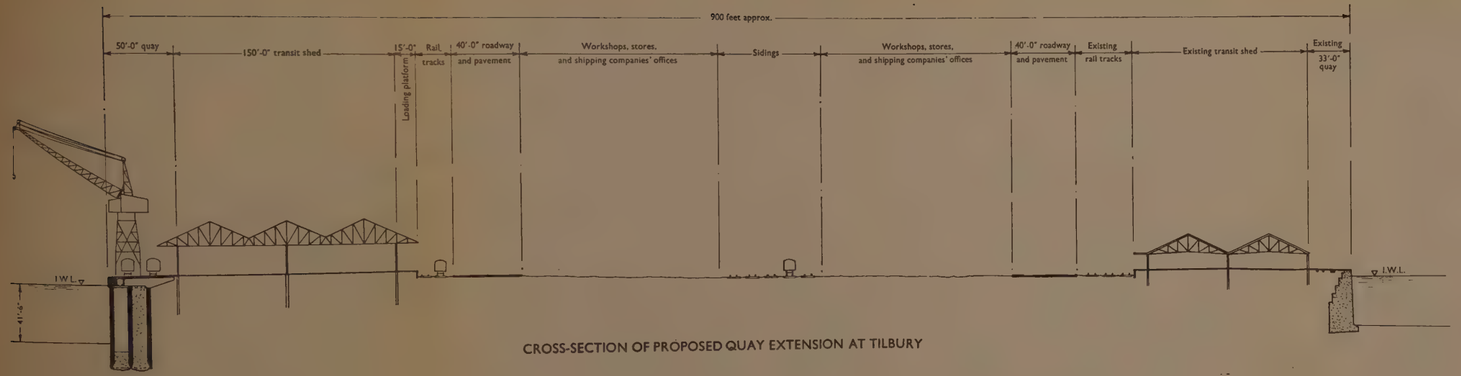
Author	*Title*	*Published*
L. M. Bates	"The Londoner's River"	F. Muller Ltd, 1950
Alan Bell	"The Port of London, 1909–1934"	The Port of London Authority
Alan Bell	"The Said Noble River"	The Port of London Authority
W. G. Bell and T. R. Wray	"The Thames from Chelsea to the Nore"	John Lane, The Bodley Head, 1907
Hilaire Belloc	"The Historic Thames"	H. M. Dent & Co., 1907
Hilaire Belloc	"The River of London"	T. N. Foulis, 1912.
Sir Walter Besant	"London"	Chatto and Windus, 1912
Sir Walter Besant	"East London"	Chatto and Windus, 1903
Sir Walter Besant	"South London"	Chatto and Windus, 1901
Sir Walter Besant	"Westminster"	Chatto and Windus, 1897
Sir Walter Besant	"The Thames" ("The Fascination of London" series)	Adam and Charles Black, 1903
G. H. Birch	"London on Thames"	Seeley & Co. Ltd, 1903
A. H. J. Bown and C. A. Dove	"Port Operation and Administration"	Chapman & Hall, 1950
Sir Joseph Broodbank	"History of the Port of London"	Daniel O'Connor, 1921
Dr Brysson Cunningham	"Cargo Handling at Ports"	Chapman & Hall, 1923
Dr Brysson Cunningham	"Port Administration and Operation"	Chapman & Hall, 1925
J. A. Dunnage	"The Importers' Handbook"	
Lincoln Gordon	"The Public Corporation in Great Britain"	Oxf. Univ. Press, 1938
H. Gosling	"Up and Down Stream"	Methuen & Co. Ltd, 1927
John Herbert	"The Port of London" ("Britain in Pictures" series)	Collins, 1947

Author	*Title*	*Published*
F. C. Hodgson	"Thames-side in the Past"	G. Allen & Co. Ltd, 1913
Rodwell Jones	"The Geography of London River"	Methuen & Co. Ltd, 1931
S. R. Jones	"Thames Triumphant"	The Studio Publications, 1943
S. R. Jones	"London Triumphant"	The Studio Publications, 1942
A. G. Linney	"Peepshow of the Port of London"	Sampson Low, Marston & Co. Ltd, 1930
A. G. Linney	"Lure and Lore of London's River"	Sampson Low, Marston & Co. Ltd, 1932
A. G. Linney	"Pocket Guide to the Docks of London"	Sampson Low, Marston & Co. Ltd, 1930
R. S. MacElwee	"Ports and Terminal Facilities"	McGraw-Hill, N.Y., 1918 (2nd Ed. 1926)
Hilda Ormsby	"London on the Thames"	Sifton, Praed & Co. Ltd, 1923 (2nd Ed. 1928)
Sir David Owen	"The Port of London—Yesterday and Today"	Harrison & Sons Ltd, 1927
Sir David Owen	"Ports of the United Kingdom"	Allman & Son Ltd, Rev. 1949
E. Arnot Robertson	"Thames Portrait"	Ivor Nicholson and Watson Ltd, 1937
W. A. Robson	"The Government and Misgovernment of London"	George Allen and Unwin Ltd, 1939
F. C. Thacker	"The Stripling Thames"	F. S. Thacker, 1909.
F. C. Thacker	"The Thames Highway"	
	Vol. 1. "General History"	F. S. Thacker, 1914
	Vol. 2. "Locks and Weirs"	F. S. Thacker, 1920
A. G. Thompson	"The Romance of London River"	Bradley & Son Ltd, 1934
A. G. Thompson	"Scrapbook of London River"	Bradley & Son Ltd, 1937
A. G. Thompson	"The Thames from Tower to Tilbury"	Bradley & Son Ltd, 1939
A. G. Thompson	"London Bridge and the Pool"	Allman & Son Ltd, 1949
H. M. Tomlinson	"London River"	Cassell & Co. Ltd, 1912.

PAPERS PUBLISHED BY THE INSTITUTION OF CIVIL ENGINEERS
(in chronological order)

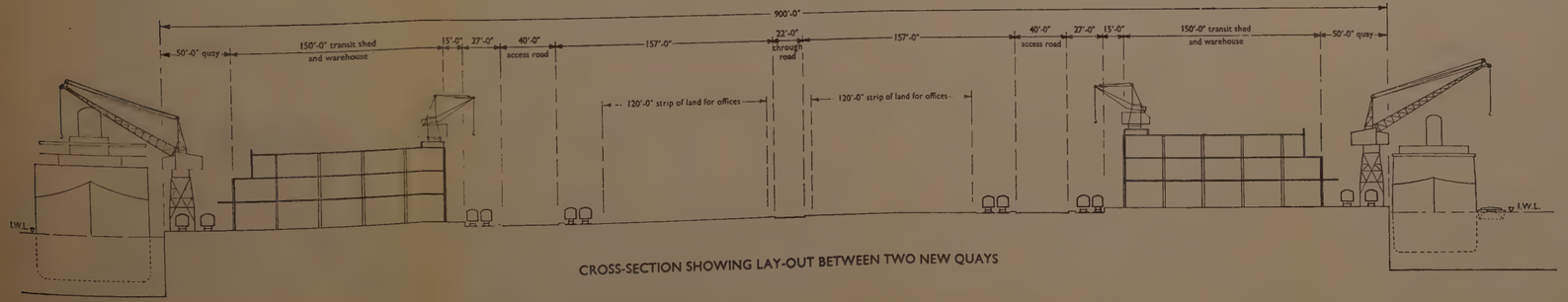
Year	*Author*	*Title*	*Location*
1835	M. A. Borthwick	"Memoir on the use of cast-iron in piling, particularly at Brunswick Wharf, Blackwall"	Trans. Instn Civ.Engrs, vol. I, p. 195
1859	W. J. Kingsbury	"Description of the entrance, entrance lock and jetty walls of the Victoria docks; with a detailed account of the wrought-iron gates and caissons, and remarks upon the form adopted in their construction"	Min. Proc. Instn Civ. Engrs, vol. 18 (1858–59), p. 445
1866	E. Clark	"Hydraulic-lift graving dock"	Min. Proc. Instn Civ. Engrs, vol. 25 (1865–66), p. 292
1872	L. F. Vernon Harcourt	"Description of the New South Dock, in the Isle of Dogs, forming part of the West India Docks"	Min. Proc. Instn Civ. Engrs, vol. 34 (1871–72, Pt II), p. 157
1877	J. B. Redman	"The River Thames"	Min. Proc. Instn Civ. Engrs, vol. 49 (1876–77, Pt III), p. 67

FIG. 6



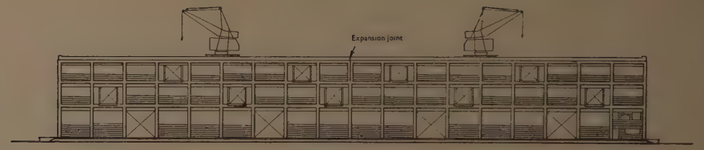
CROSS-SECTION OF PROPOSED QUAY EXTENSION AT TILBURY

FIG. 7

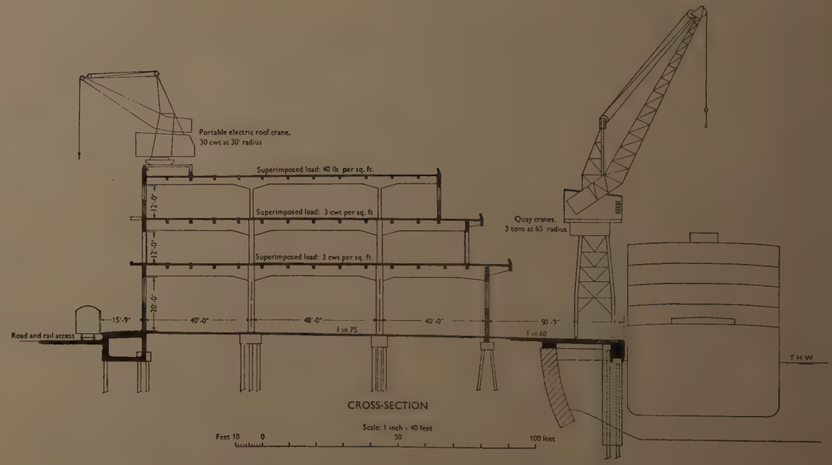


CROSS-SECTION SHOWING LAY-OUT BETWEEN TWO NEW QUAYS

FIGS 8



ELEVATION FROM ROAD
Scale: 1 inch = 80 feet



CROSS-SECTION
Scale: 1 inch = 40 feet

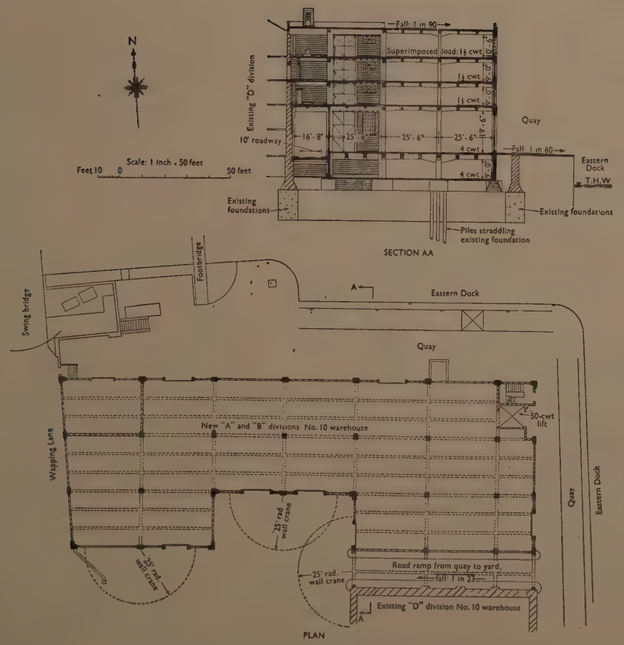
WEST INDIA IMPORT DOCK. NOS 10 AND 11 SHEDS AND NEW FALSE QUAY

G. A. WILSON

WILLIAM CLOWES & SONS, LIMITED: LONDON

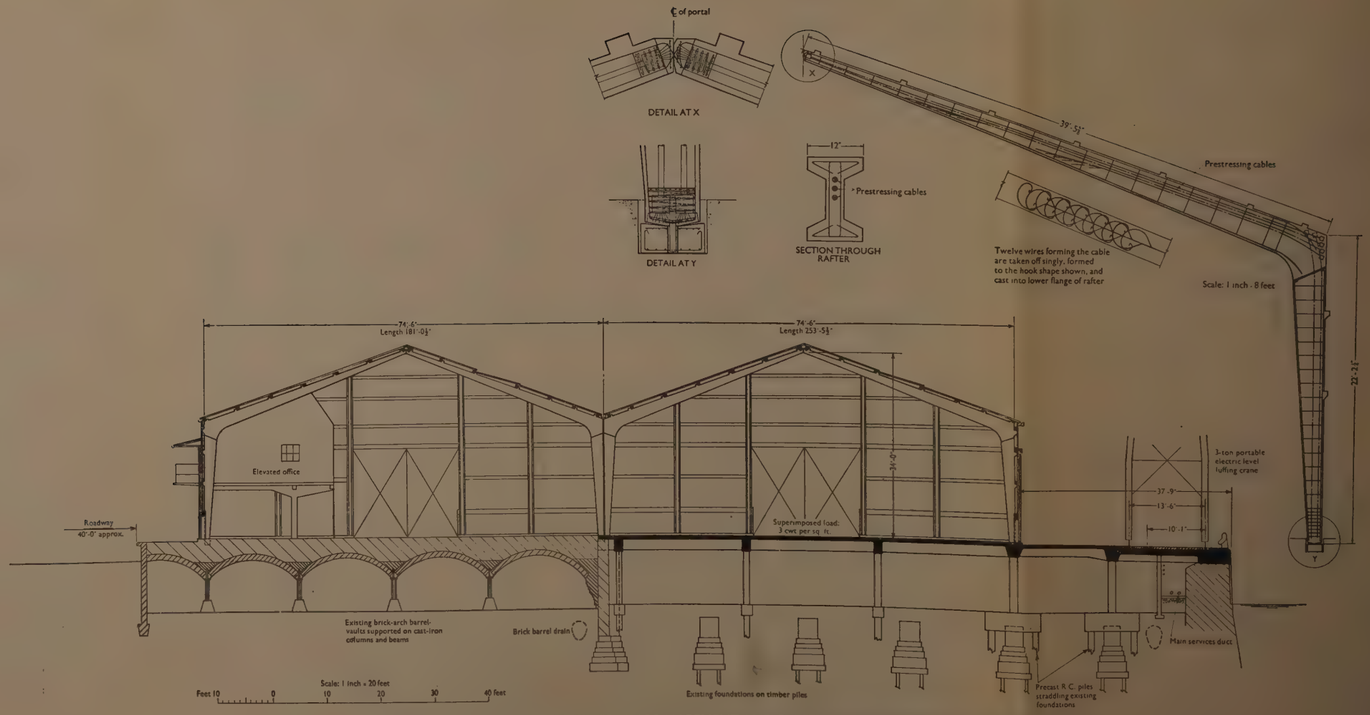
PORT OF LONDON AUTHORITY ENGINEERING WORKS, 1952

FIGS 11



RECONSTRUCTION OF NO. 10 WAREHOUSE, EASTERN DOCK

FIGS 14



EASTERN DOCK, NO. 19 SHED, GENERAL ARRANGEMENT AND DETAILS OF PRESTRESSED CONCRETE BUILDING

Year	Author	Title	Location
1886	B. H. Martindale	"Demolition of the North-East Wall of the Gallions Basin, Royal Albert Docks, on the 23rd of April, 1886"	Min. Proc. Instn Civ. Engrs, vol. 86 (1885–86, Pt IV), p. 329
1895	J. F. Scott	"The Construction and Equipment of the Tilbury Docks"	Min. Proc. Instn Civ. Engrs, vol. 120 (1894–95, Pt II), p. 276
1896	F. E. Duckham	"Grain Appliances at Millwall Docks"	Min. Proc. Instn Civ. Engrs, vol. 125 (1895–96, Pt III), p. 296
1897	H. F. Donaldson	"Cold Storage at the London and India Docks"	Min. Proc. Instn Civ. Engrs, vol. 129 (1896–97, Pt III), p. 1
1909	Magnus Mowat	"Some Recent Grain-handling and Storing Appliances at the Millwall Docks"	Min. Proc. Instn Civ. Engrs, vol. 177 (1908–09, Pt III), p. 58
1922	F. M. G. Du-Plat-Taylor	"Extensions at Tilbury Docks, 1912–1917"	Min. Proc. Instn Civ. Engrs, vol. 215 (1922–23, Pt I), p. 165
1923	Asa Binns	"The King George V Dock, London"	Min. Proc. Instn Civ. Engrs, vol. 216 (1922–23, Part II), p. 372
1931	Sir Cyril Kirkpatrick	Presidential Address. "The Tidal Thames"	Min. Proc. Instn Civ. Engrs, vol. 233 (1931–32, Pt I), p. 1
1935	F. W. D. Davis and William MacKenzie	"Major Improvement-Works of the Port of London Authority, 1925–1930"	Min. Proc. Instn Civ. Engrs, vol. 240 (1934–35, Pt II), p. 258
1938	A. L. Wheeler	"Some Aspects of Dock Reconstructions, with Particular Reference to Dredging (Royal Victoria Dock)"	Chairman's Address to Association of London Students, 16 Nov. 1938
1939	R. R. Liddell	"Improvements at the Royal Docks, Port of London Authority"	J. Instn Civ. Engrs, vol. 10, p. 283 (Jan. 1939)

PAPERS PUBLISHED BY THE INSTITUTION OF MECHANICAL ENGINEERS

(in chronological order)

Year	Author	Title	Location
1878	C. Elwin	"Floating Dock at the Victoria Graving Docks"	Proc. I.Mech.E., 1878, p. 139
1921	R. E. Knight	"Discharge of Grain Cargoes in the Port of London, by Pneumatic Elevators"	Proc. I.Mech.E., 1921, vol. 1, p. 917
1930	R. J. N. Willcox	"Maintenance of a Dredging Fleet"	Proc. I.Mech.E., 1930, vol. II, p. 1225
1932	Asa Binns	"Recent Developments in the Mechanical Equipment of the Port of London Authority"	Proc. I.Mech.E., vol. 122 (1932), p. 575
1940	Asa Binns	Presidential Address. "Mainly the Port of London"	Proc. I.Mech.E., vol. 144 (1940), p. 50

OTHER PAPERS

Asa Binns, Presidential Address, "The Thames and its Docks." Trans. Instn Engr in Charge, vol. 42 (1936–37), p. 124.

H. J. Deane, "The Charterhouse Street Cold Stores of the Port of London Authority." Trans. Concr. Inst., vol. 9, p. k/1.

J. Thomas, "The Blowing up of the Old Dock Wall, Royal Albert Docks." Trans. Inst. Mar. Engrs, vol. 2, 1890–91.

Discussion

Mr Rudolph Glossop observed that the design of the transit shed at No. 19 Berth, Eastern Dock, London Dock, was based on a three-hinged portal frame, and so far as he knew, it was the first structure of its kind to be built in Great Britain. He then displayed a series of slides illustrating some practical details of its construction.

Each portal frame was composed of four comparatively simple precast units—two top booms and two vertical booms—the maximum weight of any unit being 3·1 tons, which was well within the capacity of an ordinary mobile crane. The vertical booms could be handled without prestress, but the top booms were designed to be stressed before removing from the casting bed. On the whole, those members had been found quite easy to handle on the site, although it had been necessary to be very careful to use the correct lifting points on the top boom. Those were at 2 feet from the tapered end and 9 feet from the outer end. As could be seen from the first slide, that construction gave a span of 74 feet and plenty of head-room clear of obstruction, so that it was well suited to a building in which cargo was to be moved and stacked.

All the members had been cast on the site, the concrete being mixed in an ordinary 10S mixer and barrowed to the shutters. The mix had consisted of 5¾ cubic feet of coarse aggregate ($\frac{3}{4} - \frac{3}{16}$ inch), 4 cubic feet of moist sand, and 2 cwt of Portland cement. The water/cement ratio had been 0·3, so that about 1 gallon of water had been added for every bag of cement. It was interesting to note that the natural water-content of the aggregate was usually about 1½ gallon per bag of cement, so that slight variations in the natural moisture-content of the aggregate had been important and careful site control had been necessary.

The results obtained from that mix had been:

Strength at	3	days	(average	value)	:	4,720 lb.
,,	,,	3	,,	(	,,	,,	) : 5,670 lb.
,,	,,	14	,,	(	,,	,,	) : 6,540 lb.
,,	,,	28	,,	(	,,	,,	) : 6,980 lb.

For the large number of cubes tested, the standard deviation had been

± 716 lb., and the coefficient of variation had been 12½ per cent. That, according to the Stanton Walker scale, could be described as excellent.

Mr Glossop said a mix of that kind required intense vibration if it were to be placed in narrow members carrying duct tubes and reinforcement. For the case in question, eleven " Triller " vibrators had been attached to each shutter for an upper boom member, and in addition one immersion vibrator had been used at the ends ; it could not be used over the greater portion of the boom, since in the 4-inch web there was no room to insert the vibrator alongside the cables. For that portion of the work, two men had punned the concrete into place.

To make a concrete of that exceptional quality required no special plant, but it did require careful supervision. As a consequence, it was expensive —perhaps four or five times the price of ordinary concrete. It was also expensive in labour.

The average time taken to cast one upper-boom member had been 1¼ hour, and for a vertical-boom member the time had ranged from ½ to ¾ hour.

The mild-steel reinforcement provided in the vertical boom was for handling purposes only. In the top boom it was for crack distribution, since that member was stressed before removal from the bed.

Four Freyssinet cables had been threaded into the vertical boom and stressed before the boom was lifted, so as to ensure that the cone fastening at the bottom was tight. Once that member was in position, there was no method of checking whether a true elongation had been obtained or whether some slipping might be taking place in the cone, which was by then out of reach.

When the vertical booms were in place and secured with a scaffolding frame, the upper booms had been picked up by a travelling crane and lowered on to the falsework, the vertical cables being threaded through the ducts as the member was lowered into place.

The falsework had been set so that a space of slightly less than ¾ inch was left between the contact surfaces of the two booms. A light timber frame had then been pulled into place to prevent any slight relative movement between them and to act as a ledge from which jointing compound could be caulked into place with special tools. That process had been evolved after some experiments. The jointing consisted of an earth-dry 1 : 1 sand-cement.

A period of from 18 to 20 hours had been allowed for that jointing to acquire strength, before the vertical cables had been stressed. The four main cables had then been stressed diagonally and in pairs, and during the stressing of each pair the jacks had been operated simultaneously.

The falsework had been designed on the site and had worked very well. It consisted of a structure of three inter-connected tubular scaffolding towers, and it could be quickly rolled into place. One end of the top boom had been carried on folding wedges and the other end had been supported by

the central tower. The whole set-up had been extremely convenient. The frames were at 18-foot centres, and a complete bay could be placed in the 24 hours.

In order to distribute wind stresses, prestress had been applied through longitudinal beams connecting the four last frames at either end of the shed. Finally, a two-wire cable was carried throughout the length of the building in the ridge member and was lightly stressed to a total load of 5 tons.

The whole operation of casting and erecting that shed had been carried out without any serious technical hitches, but there was no doubt that for that kind of work to be successful, a very high standard of workmanship and constant expert site supervision were essential.

Mr R. A. Stephenson observed that although the engineering organization of the Port of London Authority was, broadly speaking, the same as that favoured by the Mersey Docks and Harbour Board, there were certain points of difference. The Board preferred that all maintenance work—except very highly specialized operations—should be done by direct labour. That preference also applied to operational functions, for example, the manning of pumping stations. In that way, they felt, the quality of the workmanship could invariably be relied upon, and there was the additional advantage that quantity surveyors were not needed.

The number of men employed on maintenance work at the Liverpool docks was 3,150, which compared with the number of men employed on the London docks. The area and length of quays involved at Liverpool was slightly less than at London, although direct comparisons were very difficult to make. Liverpool employed 816 men on floating plant and 1,120 in the Board's own workshops and dockyards.

Mr Stephenson said that the problems of conservancy on the Mersey were somewhat different from those of the Thames, in that the Mersey served not only Liverpool docks but also other self-governing ports. Stevedoring at Liverpool was done by private firms under licence and they, and the shipping companies which they served, could exercise some influence on the lay-out of quays and sheds.

There were great similarities, too, in finance. Liverpool had a statutory sinking fund, designed to provide for the debt incurred in capital expenditure in 90 years. That was supplemented by a non-statutory renewals and depreciation account, designed to meet short-life assets. It was always a very vexed question as to what extent the present should be prejudiced in a bad year by payments made into such funds, which were designed to protect the future. In other words, should payments be constant in good and bad years ?

London, although an ancient port historically, differed from Liverpool in the age of the docks catering for modern trade. It was the capital schemes decided upon in 1911, whose tremendous extent had been indicated in Sir Joseph Broodbank's book, quoted in the Paper, which had created the major part of the modern dock system at London. The expansion of

the docks thus created had been met by an increase of trade. In the same way, at Liverpool, in the first half-century after the constitution of the Dock Board in 1858, the corresponding expansion had been met by a corresponding increase in trade. Today, however, they were not quite so happily placed, because they were faced with the need for modernization, but trade seemed to be virtually steady. Perhaps London would one day be faced with the same problem.

Mr Stephenson quoted a few tonnages to show how Liverpool compared and contrasted with London. The tonnage of goods handled at Liverpool and Birkenhead in 1952, excluding bulk oil and livestock, amounted to 15,145,854, made up as followed :—

Imports :	Foreign	7,959,649
	Coastwise	1,134,703
Exports :	Foreign	4,507,762
	Coastwise	1,543,740

Of those tonnages, 55 per cent of the disposal and 74 per cent of the assembly of goods for foreign ports had been handled by road vehicles—only 16 per cent import and 15·5 per cent export by rail. For coastwise vessels, the figures were about 42 per cent export and 49 per cent import by road, and 16·5 per cent export and 31·6 per cent import by rail. There was not a great deal of barge traffic at Liverpool—only 16 per cent of the imports and 10 per cent of the exports of the foreign trade and very little of the coastwise trade. Liverpool had been called a road port, and road congestion was certainly bad at times, but not quite so bad as the Author had suggested in the Paper.

Mr Stephenson then showed a series of lantern slides illustrating the development of transit sheds at Liverpool. He pointed out that the columns in the sheds built recently were spaced at 25-foot centres along the dockside and roadside, and at 50-foot centres under the valleys. The dockside doorways occupied every second bay between columns, and the roadside doorways every fourth.

The slides showed a great variety of arrangements, all of which had their advantages and disadvantages ; the reason for that variety was the private stevedoring system. Cargoes varied and the stevedores sometimes preferred to use ship's gear rather than the cranes if the cargo were of a type which could only be handled slowly in the hold. That tended to limit the width of the quay. The rate of discharge and loading was, of course, to a great extent governed by the speed with which operations were carried out in the ship's holds.

Another slide showed a design which Mr Stephenson considered to be almost ideal. The cranes were mounted on the roof of the shed, the only disadvantage of which was that it limited their out-reach to a certain

extent because, apart from the rather heavy wheel-loadings unavoidable with a long jib, it restricted the use of the crane in high winds. With a 30-foot quay margin it was reasonable to reckon on an out-reach from the quay edge about 50 feet, but if there were a wider quay margin it might be necessary to reduce that.

The provision of four 3-ton cranes and one 5-ton crane to a ship's length —about 600 feet—had been adopted as standard at Liverpool. The speeds of the motions were much the same as those described for London—perhaps a little faster, except for travelling, for which the Liverpool figure was distinctly lower. Floor loadings at Liverpool had been standardized at 3 tons per square yard on the ground and 25 cwt per square yard on the first floor of a double-storeyed shed. Mobile cranes were used extensively. That had led to the adoption of a clear height of 22 feet for doorways, whilst internally, in the shed, a clear height of 24 feet to trusses or beams was provided.

Mr Stephenson said the number of mobile cranes owned by the Board was 171. During the 1939–45 war the number had risen to 245. In addition, a large number of privately owned mobile cranes were in use.

A further slide showed how roof cranes could be bunched together to work two or more cranes in a hatch quite comfortably. By using the luffing operation only, a very speedy working could be obtained without the cranes fouling each other. The cranes shown were of the crank-operated luffing type, as were those in the Gladstone Docks.

The next slide illustrated how extremely difficult it would be in present circumstances, with mixed cargoes, to introduce the pallet system at all effectively. Mr Stephenson believed that in the United States, where it had been possible to standardize sizes, the pallet system worked very well with fork-lift trucks, although breakages still occurred. Experience with fork-lift trucks in Liverpool could, in general, be said to be the same as that described in the Paper.

It was very interesting to compare the systems of dredger lubrication at London and Liverpool. It seemed that at London the buckets were small. The buckets on the Board's dredgers had a capacity of 21 cubic feet, and ran at speeds of 54 to 66 feet per minute. The average weekly tonnage quoted for the P.L.A. dredgers appeared low, but the working time was not stated. The most recent bucket dredger at Liverpool, the "Mersey Engineer," had in the previous week loaded a 1,000-ton hopper in 50 minutes from a depth of 48 feet. That dredger had lubricated roller shafts and bearings, but the difference in the rate of wear of tumblers, buckets, pins, and links was little different from the wear on the older dredgers which had no such provision. The results recorded in the Paper for the wear after 40 weeks might be attributable to the small dimensions of the dredger, but, even so, they were astonishing.

Mr John Palmer strongly recommended any engineer who was engaged on the design of docks and harbours to study and re-study the interesting

paragraphs in the Paper on the subject of port cranes, their working and grouping. The Author had admitted that the 3-ton crane was normally quite ample, but there had to be a 5-ton crane on hand and it was stated in the Paper that the latest P.L.A. practice was to provide one 5-ton and five 3-ton cranes at each berth. Mr Palmer said he did not find those figures reconcilable with Table 3 and with the statement that, under recent contracts, eighty-seven 3-ton and twenty-five 5-ton cranes had been ordered. One explanation might be that Table 3 included the eighty-seven 3-ton cranes as already in use; obviously it did not include the twenty-five 5-ton cranes. In any case, the best ratio obtainable from the figures was 402 to 29 or, say, 13 to 1, which was a long way behind the desirable ratio of 5 to 1.

Mr Palmer asked the Author why the gauge of the portal crane had been increased to 18 feet instead of 13 feet 6 inches. Had there been a change in the loading gauge of the railways or was it to cater for bulky loads on road vehicles? Referring to the statement in the Paper that: "Ships at deep-water berths generally have five or six hatches . . . and at first-class berths in London six or more cranes are provided," Mr Palmer asked the Author how many tons of general cargo were unloaded on the average from one hatch in one day's shift.

As had been pointed out, a large increase in road transport was fundamental to any port lay-out today, and Table 2 showed the astonishing change in the short period of 12 years. Mr Palmer had a lay-out under preparation in which he had incorporated specific lanes for road traffic moving on to the jetty, two separate lanes for road traffic moving off the jetty, and, in addition, separate and entirely clear lanes for road traffic—whether lorries or trailers—standing still to be loaded or unloaded. He was sure that if traffic was allowed to roam at will over the whole surface of a quay or a jetty the result would be indescribable confusion. If road traffic was to give the service to ports in the future that railway traffic had given in the past 50 years or more, then road vehicles would have to put up with being marshalled and regulated as the railway trucks had done.

The Author had referred to the arrangements of roads and railway tracks in Figs 6 and 7, Plate 1, and had picked on Fig. 7 as the "ideal." Mr Palmer considered that it was not an ideal arrangement to split each of the two groups of four railway tracks on each side of the shed. He preferred the road-rail lay-out shown in cross-section in Fig. 6.

Mr Stephenson had referred to travelling cranes on the top of warehouses, but Mr Palmer was glad to note the Author's comment that in some places lack of space had made it necessary to combine transit sheds and warehouses, "which otherwise would not be advocated." Mr Palmer was in full agreement with that.

He went on to refer to the quotation, on p. 558, from a book by Sir Joseph Broodbank, part of which read: ". . . the ideals of engineers, if unchecked by commercial expediency, might easily be the ruin of the

greatest port in the world." The date of Sir Joseph Broodbank's criticism had been carefully pin-pointed as the year 1910, which meant that he had been specifically criticizing the first Chief Engineer of the P.L.A. Mr Palmer said he had at one time been rather well acquainted with that gentleman and, in his opinion, the recommendation for spending £700,000 on repairs to old properties was a secondary and trivial matter. He believed that that particular Chief Engineer's main contribution to the greatest port in the world had been to produce, in 1910, a scheme for nine major capital improvements spread over the 30-mile length of the River and estimated to cost £14 million. He suggested that if it had not been for the materialization of the ideals of that engineer, there would be today in the Port of London no King George V Dock and no Dry Dock or Passenger Landing Stage at Tilbury.

Much more important than all the points dealt with by Broodbank was the question of obsolescence. Surely the great problem for any port or harbour authority was always: " Will our entrance locks be large enough for the ships trying to use them 10 or 20 years hence ? Will our dry docks, jetties, and quays have sufficient depth of water 10 years from now ? "

Mr Palmer said he had been told that one of the giant tankers recently launched at a major port in the north of the British Isles would have to steam many miles, after it left the fitting-out berth, to another port to go into dry dock, because there was no dry dock in its home port of sufficient depth to take it !

Were the P.L.A.'s dry docks going to be wide enough and long enough to take the giant tankers which were already calling regularly at the Isle of Grain ? Mr Palmer quoted the following figures : the King George V Dry Dock was 750 feet in length and had a 100-foot entrance width ; the new Mauretania was 772 feet in length and had an 88-foot beam ; the the Tilbury Dry Dock would also be too short.

Many of the entrance locks of the P.L.A. had been reduced in size from the dimensions recommended in 1910. The recommended length of the Tilbury new entrance lock had been 1,050 feet and its recommended width, 130 feet ; it was actually built only 994 feet in length and 110 feet in width. The recommended length of the entrance lock of the King George V Dock had been 850 feet and the recommended width, 110 feet ; when built, it was in fact reduced to 800 feet by 100 feet.

Mr Palmer believed that what the Port of London needed, if it was to be the greatest port in the world, was plenty of idealism from engineers and not too much commercial expediency.

Mr E. A. Lewis observed that he had been particularly interested in the part of the Paper dealing with mechanization and the fork-lift truck. The Author had written :—

> " Concerning the much discussed fork-lift truck, with its attendant packaging and labour problems, if packing could be revolutionized

and palletization generally introduced, the future of the appliance would be assured, but at the present time its chief claim to fame is the latest idea."

Mr Lewis disagreed strongly with that comment, and gave a brief idea of what palletizing involved, indicating how the fork-lift truck was being used in the docks in a very simple way. That had no relation whatever to the general palletization of cargoes for throughout movement.

General adoption of the pallet system meant that the factory would make up a unit load on a small and cheap pallet which formed part of the pack. The pack, with the pallet underneath, was handled throughout, until it arrived at the consumer, by the fork-lift truck. That was at present " under very active consideration," and he had no doubt that in about 10 years' time most of the problems would have been overcome and it would be in general use. But the " throughout movement " method would not solve the docks' problems ; it would merely add to them.

Mr Lewis said that it would be necessary to treat the palletized units as individual packages—indeed, as normal cases—because the pallet had to be a special size for use in railway trucks and such places. When the unit arrived at the dock shed it would have to be placed on another type of pallet.

The special pallet which the Author had described had been devised and used in London. That was a pallet-landing board, and the great advantage was that it could be lifted on board ship or taken off the ship by engaging hooks in the four eyes, one on each corner. A very common piece of cargo-lifting gear was used, known as a " bunch of fours."

Fork-lift trucks had recently been introduced for handling Spanish oranges imported into London. That fruit had been imported in great quantities that season and it was necessary to discharge it rapidly so that the ship could be turned round as quickly as possible. The oranges had to be handled very carefully and sorted, which provided a great problem.

When the oranges had been handled manually, the gang on board the ship, in the hold, had loaded the cases on to ordinary wooden landing boards, which were about 5 feet square, with an eye at each corner. The boards were lifted on to the quay, where the cases were manually handled by the gang, consisting of twenty men. Each man hand-trucked cases into the shed and to the correct " bay " for that particular mark. It had never been possible to sort as quickly as the men on board could discharge, so the latter were generally working at three-quarters or half pace. The number of men receiving and sorting could not be increased, because five gangs meant a hundred men, which was too many for efficient working.

The following solution had been adopted : instead of a normal landing board, the pallet-landing board was used and the men on board loaded that pallet in the same way—about 35 to 40 cases on each pallet. The pallet was hoisted to the quay by crane and was immediately taken over by the

fork-lift truck and moved into the shed, where seventeen were now engaged. The operation did not reduce the total number of men, because three men were needed with the fork-lift truck and pallets on the quay. All the seventeen men were sorting, however, instead of a lot of them hand-trucking from ship to shed—which took some time on the 50- to 60-foot-wide quays.

The result was that the men on board never had a set waiting on the quay. They knew that all they loaded would at once be whisked away. The system had not been in operation for very long, but the normal average output of 800 cases per gang had been stepped up to 1,000—and it was expected to achieve a still higher rate.

Mr Lewis suggested that that disposed of the error into which the Author had fallen—the error of believing that the general introduction of the pallet system was necessary before the fork-lift truck could be used in the docks.

Mr P. A. Scott observed that the Author had given the proportion of 3-ton to 5-ton cranes as 5 to 1. He himself would have suggested 3- and 6-ton cranes for operation abroad, because in some of the less developed countries the ports tended to have slightly heavier sling loads than ports in Great Britain. For that reason, as well as to provide a margin of safety against the rougher handling a crane was apt to get in those countries, he suggested 3- and 6-ton cranes. With the 6-ton he preferred two gears, so that it could be run at the normal speeds with 3-ton loads and at half or reduced speeds with 6-ton loads. That avoided isolating the 6-ton crane and prevented the difficulty of complicated cranage charges.

He was grateful to Mr Lewis for his remarks on mechanical handling, because he had intended to say that the adoption of the pallet system would have to be delayed until the introduction of a universal system, whereby goods could be put on to pallets in the factories and not removed until they were delivered to the warehouse of the man in another country who had bought them. It might then be possible to envisage a world-wide system of pallet exchange; it could be arranged so that pallets were not necessarily returned to their owners, but that the latter would be credited with the correct number of pallets.

Again on the subject of mechanical handling and the fork-lift truck, Mr Scott observed that the Author, on p. 565, in discussing the possible reconstruction of a shed, had suggested that if fork-lift trucks were to be used to any great extent, they would consider the removal of the platform at the rear of the shed. That was a problem which cropped up rather a lot at present, when universal use was not being made of the fork-lift truck. Supposing the new shed were designed without a raised platform at the back for loading the trucks or lorries, and supposing that fork-lift trucks were not adopted entirely, one would be faced with the problem of lifting the goods from the floor to the deck level of the truck. Was it not better to continue with a loading platform at the rear, because could not a fork-lift truck equally well load the lorry or railway truck from its deck level?

In those circumstances, they would be equipped for either fork-lift trucks or ordinary trolleys.

On p. 564, the Author had said :—

> " Lack of space makes it necessary to combine transit sheds and warehousing, which otherwise would not be advocated. . . ."

Mr Scott said he whole-heartedly supported that comment, provided that there was sufficient space at the rear of the port. It always seemed to him a heresy to allow the transit-shed area to be cluttered up with storage sheds. The transit-shed and dock area should be regarded as a live area and the storage should be taken into the dead area at the back, where traffic would not interfere with traffic coming to and from the ships.

Mr Scott then referred to the apparently enormous cost of equipping a berth with mechanical equipment, as quoted by the Author. Even then, it had to be considered as almost worth while if the saving in the turn-round time of a ship were as great as the Author had claimed. After all, the essence of all port working was to get the ships away again quickly.

Mr Scott said he was also interested in the use of aluminum sheeting. He had been surprised to read, on p. 568, that aluminium was used on shed walls above 5 feet from the ground. Obviously, the bottom part should not be too fragile, but was aluminium also used on the quay-side face from 5 feet upwards ? He would have thought that from 5 feet upwards it was still subject to heavy damage from swinging loads from cranes in a wind or under imperfect control.

The use of aluminium in tropical countries was to be advocated because of its cooling properties, but in a port it was also necessary to bear in mind the trouble it caused, at certain times of the day, when it reflected the hot tropical sun back on to the captain's cabin or the passengers' cabins ! Had the Author had enough experience of the use of aluminium to know whether it stood up to the hard wear it was apt to get in a port ?

Finally, Mr Scott dealt with a reference to quantity surveyors, on p. 554. He was sure that the reason for employing quantity surveyors by the P.L.A. were good, but what could a quantity surveyor do that an engineer could not do ? A man could not be an engineer until he had learned to do quantity surveying—particularly in civil engineering. That the contractor and the Authority should be able to agree on one single quantity surveyor was very commendable ; Mr Scott could not imagine a contractor and an employer agreeing on one civil engineer to take out the quantities ! He did not know why it was that quantity surveyors attracted an impression of infallibility and impartiality which did not attach itself to engineers.

The only point in favour of the arrangement was mentioned on p. 557, where the Author had said that costs were reduced, " . . . partly from increased supervision by professional engineers, which has obtained more work for the same money." That was a flattering statement, if true, and

one which Mr Scott hoped could be demonstrated. It suggested that perhaps the removal from the sphere of the engineer of the humdrum business of measuring and adding up—which any engineer could do—would leave his mind free to concentrate on the technical problems.

If, however, quantity surveyor "fetish" were carried to its logical conclusion, a race of engineers would be produced of the type generally known, nowadays, as back-room boys or technicians. They would have no experience of finance and the almost commercial outlook which was so necessary in design. They would merely be able to design something so that the quantity surveyor could take out the costs and tell them afterwards. Then, indeed, Sir Joseph Broodbank's criticism would perhaps become applicable and the broad-minded administrative engineer would become a man of the past, and would have to be replaced by the broad-minded administrator without engineering experience, to the detriment, Mr Scott thought, of the works they were discussing.

Mr C. W. N. McGowan observed that, on p. 572, the Author had referred to "... the transition from the 30-cwt non-luffing hydraulic cranes of 1913 or earlier to the 5-ton level-luffing electric cranes which are now being purchased...." Whilst realizing that the Paper gave a very interesting survey of a unique opportunity given to a public authority to recover from colossal war damage in a period of 7 years, and so far as finances would allow, it was as well to visualize whether the direction of post-war mechanical port development so described had been, in fact, the right direction when considered in comparison with similar development in the United States. Development there had been basically on different lines, though not necessarily better lines.

First, no single pier in New York was equipped with a dockside crane. The cargo was transferred between pier and hold on the Burtoning system, employing ships' gear and a steel cargo mast which ran the length of the pier above the transit shed. Those two systems together had been invariably used in New York harbour since the date of the first steamship. Floating cranes up to 300 tons were used for heavy lifts.

Secondly, the Burtoning system was claimed to present greater flexibility in handling merchandise when used with pallets and fork-lift trucks. The practice in the United States was an allocation of about 700 pallets per truck.

Thirdly, ship's gear had been developed to a high degree of efficiency and versatility. Over there, the price of the travelling level-luffing quayside crane today was approximately three times the price of ships' modern gear.

The principle was that a ship was regarded as a trader with something to deliver or to load. Why not, therefore, let the owner of the ship carry out his own loading and discharging?

The result was that the New York docks presented an extraordinarily clean lay-out because of the complete absence of dockside cranes. After

having been accustomed to the general practice in Great Britain, the appearance in the United States was arresting.

Mr Palmer had referred to the problem of obsolescence. The practice in Europe was that the harbour authority would carry the whole of the cost of maintenance, improvement, modernization, scrapping, and replacement of all the mechanical equipment, whereas in the United States the harbour authority had been freed from that load and that capital and revenue expense.

It was admitted, of course, that the range of tides in the United States was low compared with the tides in Europe. It was probably the case that ships' gear would not be so easy to operate in Europe where tides had a higher rise and fall.

Investigations on the subject had been conducted by the International Cargo Handling Co-ordination Association at the Rotterdam Conference in May 1952, as well as by the International Association of Navigation Congresses and by Dr Neumann, Chief Mechanical Engineer, Port of Hamburg. The question always put was, " Does the quayside crane increase the capacity and economic efficiency of the port ? " It was probably true to say that if longshoremen trained in Europe in the use of quayside cranes, and similar men trained in the United States in the Burtoning system, were asked to reverse their methods, there would be a big decrease in the efficiency of port handling.

Nevertheless, the challenge was ever-present. For instance, on p. 574, the Author had declared that wall-cranes had possibly reached the limit of their development, owing to drivers' visibility difficulties.

Mr McGowan thought that the European method was right in the long run.

As Mr Lewis had observed, the Author had dealt with the fork-lift truck on p. 575, by stating that the chief claim to fame of the fork-lift truck was that it was the latest idea. It was appreciated that the dock workers were suspicious of mechanization and that employers were wary of sinking a great deal of money into machines, lest it be wasted. Unfortunately, whilst casual labour in the docks was dead, the casual mentality was dying only slowly. As a result, mechanization was well behind, despite the fact that the export trade of Great Britain was now at its highest in history.

As an example of that, Mr McGowan cited the case of a Liverpool firm which had spent £6,000 on six fork-lift trucks, but nobody had used them for 6 months.

He suggested that the answer might be a greater use of pallet trucks on the lines mentioned by Mr Stephenson and Mr Scott. The importance of that had been stressed by Lord Waverley at a British Standards Institution luncheon towards the end of 1952. Mr McGowan also said that there was room for improvement in the system of handling goods or operating inside the holds of ships. He understood that a French device had been produced which was capable of increasing the rate of discharge from within the hold.

The next developments, he suggested, were the greater use of whole trains of trucks on the quayside, and the greater use of pneumatic and belt conveyors for bulk cargo.

Mr J. H. Jellett observed that he was prompted to take part in the discussion because of Mr Palmer's impassioned plea for more and bigger works for docks engineers, a plea which, in theory, he heartily supported, although one had to be a realist in those matters. Mr McGowan had touched on one aspect of the problem when he had said that the whole burden of such works fell on the port authority. It was a fact that, under the present system of charging for services in most of the ports of Great Britain, shipowners were entirely free to make their ships of whatever size, shape, length, breadth, or depth they chose, provided they could get them into the port, and the port authority could recoup themselves only on the actual tonnage; whereas the dimensions of the ship, in the inconvenience of dealing with it, might far outweigh any extra payment received because of increased tonnage.

A few years ago, Mr Jellett had had occasion to make a calculation affecting Southampton, from which he had ascertained that, from the point of view of the port authority, the total dues collected per passenger out of one voyage of the *Queen Elizabeth* was the same, within a penny or two, as the total collected per passenger if those passengers had come, as they could have come, by three voyages on the *Mauretania*! He would not emphasize the difference in capital works involved in making a port capable of handling the *Queen Elizabeth*, as compared with one capable of handling the present *Mauretania*. It was the same Chief Engineer to whom Mr Palmer had referred, who had said that the cost of the capital works at a port varied approximately with the cube of the draft of the deepest ship for which the port was intended to cater.

If the salary of the chief engineer varied in the same proportion, Mr Jellett would be pleased, bearing in mind the ships which came to Southampton! In all seriousness, however, the point he had made should be borne in mind when considering whether port facilities were suitable for the larger ships which were being built.

Today, so far as he could see, almost the whole economic advantage of building bigger ships accrued to the shipowners and very little to the port authority.

Mr Jellett congratulated the Author on the courteous way in which he had " debunked " the excessive claims of the fork-lift truck. There was no doubt but that the fork-lift truck was a very useful device but it would not do everything and it brought with it certain disadvantages. Its innovation in Britain dated from shortly after the 1939–45 war, when it had been surrounded by a certain aura from the performance which had been witnessed when it was in the hands of the Americans who occupied some of our ports during the war.

If it were to be used in the loading of upper floors of warehouses, there

were certain economic implications which could not be overlooked. Mr Jellett said that the same orange-handling problem as that described by Mr Lewis had been experienced also at Southampton, where they were using electric scooter platform trucks, combined with stillages under the landing boards, enabling each sling of cases to be brought straight into the shed where sorting took place.

*** **Professor Herbert Addison** observed that the Paper appeared to make no mention of the passenger traffic handled by the Port of London Authority, and he would therefore like to ask whether the Author could give any indication of the relative importance of that traffic in 1952 as compared with, say, 1939.

Since Professor Addison had himself had the privilege, as an incoming passenger, of using the Authority's facilities during 1952, he would like to record his impressions. Certainly his predominant feeling was one of admiration for the skill and judgement of all those who helped in any way to work the vessels into and out of Tilbury docks. The 20,000-ton mail steamer on which he had been travelling, after lying fog-bound for several hours, had negotiated the entrance lock while visibility was still poor but when river traffic was heavy. While watching that manoeuvre, he had remembered very clearly an earlier Paper presented to the Institution, in which the siting of that entrance lock had been discussed at length. He would therefore now like to ask whether, after many years' operating experience, the Authority's engineers were satisfied that the lock really had been built in the best position.

When, on that particular occasion, passengers had finally disembarked, they had had the opportunity of comparing reception facilities at Tilbury with those they had observed at an earlier stage of the voyage. At Naples, for instance, they had seen a very imposing passenger terminal building, reconstructed, so it was said, after the war. While trying to get away from Tilbury, passengers could appreciate a point raised in connexion with freight handling in the present Paper, namely, the growth in road traffic at the docks. Although a special boat-train had been provided for the journey to London, the number of motor-vehicles waiting for passengers and their friends had been so great that considerable congestion had occurred. Doubtless they would have received a more favourable impression if the ship had been able to come alongside the floating landing-stage; in any event, they had been much better off than they would have been 30 years previously, when passengers had had to come ashore in tenders. The question which arose was, therefore, were any improvements contemplated which would take into account (1) the continued construction of high-class passenger ships based on the Port of London; (2) the increase in road traffic in connexion with passenger embarkation and disembarkation; (3) the

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*** This contribution was submitted in writing upon the closure of the oral discussion.—Sec. I.C.E.

competition of new ocean terminal buildings, with improved baggage-handling facilities, such as the one at Southampton ?

One other question, which perhaps lay just outside the scope of the Paper, related to the recent disastrous high-tide and storm floods. They had caused serious damage at dock and other installations on the south side of the Thames estuary, but apparently the Authority's own installations had remained immune. If that was indeed so, it would serve as a very high testimony to the foresight with which the works had been planned.

The Author, in reply, said that Mr Glossop's description of the site works for the prestressed-concrete transit shed was a valuable contribution to the discussion but he did not propose to make further comment on that point since it seemed likely that a Paper on the building would be presented during the 1953–54 Session.

He was very grateful to Mr Stephenson for giving so many facts and figures for the working of the Mersey Docks and Harbour Board for comparison, since that made the Paper more useful, and he was interested by the suggestion that it became necessary to modernize a port one hundred years after construction. The main docks reconstruction in London had occurred almost 50 years previously and the replacement of war damage had permitted a fair amount of modernization, so on Mr Stephenson's basis, London might be considered a fairly up-to-date port.

The practice of providing one 5-ton to five 3-ton cranes, to which Mr Palmer referred, only applied to deep-water berths and the figures in Table 3 included the numerous cranes at small berths for coastal vessels, where 30-cwt cranes were adequate. The Table did not include the 3-ton cranes on order. The increase in gauge from 13 feet 6 inches to 18 feet had been proposed because the greater width permitted a more economical design of the crane structure when the duty was of the order of a 5-ton lift at 90 feet radius and the height of the underside of the crane cabin was 50 feet. Clearance between the cabin and the overhang of the ship's superstructure was also improved. The deciding reason for adopting the 18-foot gauge in preference to the 15-foot gauge which was frequently recommended was, however, that the port had already some 18-foot-gauge cranes and interchangeability was considered to be important.

Referring to the road, rail, and shed lay-outs shown in *Figs 5* and in Figs 6 and 7, Plate 1, there was a lay-out which, having regard to all the known conditions, was the optimum one for a particular site but not necessarily for any other. In the lay-out in Fig. 7, two sets of rail tracks on either side of the back road were preferred, since in that way it was possible to provide access between the road and the shed where lorries could back-up for unloading without obstructing the running lines to which access was obtained by frequent cross-overs. Rail tracks were still required on the quay for direct ship-to-rail trans-shipment.

In quoting Sir Joseph Broodbank, the Author had taken the " ideals

of engineers " as applying to maintenance, which agreed with the context. Certainly the development within the Port of London which had taken place under Sir Frederick Palmer had been the making of the modern port. It was, however, fair comment that, left to himself, an engineer might try to achieve too high a standard of maintenance. Full efficiency of plant and tidiness conducive to effort were essential, but beyond that maintenance expenditure had no economic function.

The need to keep port facilities abreast of ship development was a stimulating problem shared with airfield and highway engineers. Ships, aircraft, and vehicles had a comparatively short economical life whilst the permanent structures they required to serve them had a life three or four times as long. Since it was frequently impossible to design structures to resist the physical forces involved with a short life, it became necessary to forecast development by examining trends in recent design. That could be an unreliable procedure and, moreover, in rivers and estuaries, nature frequently provided a limit beyond which it was uneconomical to extend. If the conception of designing for obsolescence were being considered, allowance should be made for the fact that the giants of today were the normalities of tomorrow and it would only be the services at the bottom of the scale which would become obsolete. Medium-sized ships of 8,000 to 20,000 tons were producing a higher demand than ever before on the facilities available.

There was no reliable figure of wide application giving the numbers of tons of cargo which could be discharged through one hatch. However, taking a variable cargo, in a large vessel with five or six hatches, a figure of 100 tons per hatch per gang might be taken as conservative. The road traffic figures given on p. 564 had that basis. If two gangs were used on one hatch under favourable conditions, that figure might be doubled.

The Author particularly welcomed Mr Lewis's contribution to the discussion on the use of fork-lift trucks, because he was a pioneer in that technique. It was interesting to note the view that " throughout palletization " from manufacturer to distributor through the docks would add to the port operator's difficulties, but the Author hoped that when the demand arose for mass handling of standard pallets from quay to ship the engineer would be able to supply the answer. It was agreed that the use of fork-lift trucks could lead to a quicker turn-round of ships, but unless the reduction in loading time were consistent, the ship owners might not be able to take advantage of it in arranging new schedules. The type of goods which could be handled in that way at present seemed to be limited and the advantages of the fork-lift truck were correspondingly limited. It should be mentioned that the pallet and cargo boards illustrated in *Figs 16* had been patented by the firm that had manufactured them for the port.

In reply to Mr Scott's remarks concerning the proportion of 3-ton to 5-ton cranes, the proportion of five to one had been arrived at as a result of

a study of actual loads handled. London shipped goods to and from all parts of the world and it would appear that the loads experienced in London would reflect general practice in most other ports, although the proportion of heavy to light lifts might be expected to vary. In the new cranes on order for the Authority, the hoist speed for a 5-ton crane lifting 1½ ton was faster than that of a 3-ton crane with the same load. The slewing speeds were the same, but the luffing and travelling speeds of the 5-ton crane were slower. The Author had not suggested that it was necessary to consider the removal of loading platforms at the rear of sheds to enable fork-lift trucks to be used. The present need for those platforms frequently required sloping floors in the transit sheds. That was not an entirely satisfactory feature and if the development of the fork-lift truck rendered the platforms redundant, their removal should be considered to enable the shed floor to be laid flat.

Corrugated aluminium-alloy sheeting of suitable gauge was a strong and robust material almost equalling steel, but with greater deflexion for a given bending moment. With suitable purlin and sheeting-rail spacing it seemed probable that a blow that would damage aluminium alloy sheeting would also damage steel sheeting. In the Authority's experience, the bottom 5 feet of the shed wall, both on the quay side and at the rear of the shed, was most vulnerable. With wide quays, the walls above that level were unlikely to be damaged by swinging sets. Thus 5-foot-high brick perimeter walls would have been built even if steel sheeting had been provided. In another transit shed, shortly to be constructed, it had been decided to provide brick walls for the full height of the shed and a useful comparison of maintenance cost would become available.

There was much that the Author agreed with in Mr Scott's remarks about the employment of quantity surveyors. The responsibility for estimating, specifying, and financial control rested with the Authority's engineers, but where a maintenance contractor was employed on a schedule of prices basis, the services of specialists (and that was, in fact, what quantity surveyors were) were useful and economical.

The merits and demerits of the quay cranes as opposed to ships' gear, as mentioned by Mr McGowan, had formed the subject of discussion for some time. The subject had been very well reviewed by Dr Neumann of Hamburg in a recent article in the technical press. The Author viewed the problem from the standpoint that it was the duty of a public authority to provide the best service within economic limits. Shipping companies and stevedores required and, in the long run, paid for quay cranes; otherwise they would not be provided. It seemed probable that the practice of not providing quay cranes in America had developed because the finger piers in the most important port in the United States of America—namely, New York—did not lend themselves to their installation. To compensate for that, the use of ships' and other mechanical appliances had been highly developed in America and the longshoreman had, by practice, developed

a high proficiency in their use. It was not possible, in the Author's opinion, to arrive at a satisfactory comparison of the merits of the two systems from a consideration of the output per man-hour in America and Europe, for that output depended to a large extent on the complex question of labour relations.

The problems which arose from the increase in dimensions of ships, which had been raised by Mr Jellett, had already been discussed. It would appear that the system of dues in use at Southampton would, from Mr Jellett's description of it, encourage the shipping companies to build even larger ships. The problem was, of course, one which required co-operation between the interests concerned, and the Author hoped that the "Committee on the Depths in Sea Ports," set up by the British Section of the Permanent International Association of Navigation Congresses, might do some useful work.

The increased use of the mechanical handling appliances had a great effect on the design of dock structures, as mentioned in the Paper, and the increased cost of such structures had to be borne in mind in assessing the economic value of the use of the appliances.

Professor Addison's inquiry regarding the relative importance of post-war as compared to pre-war passenger traffic might best be answered by quoting the figures for the Tilbury passenger landing stage.

In an average pre-war year the inward and outward total had been slightly more than 100,000. In 1952, the corresponding figure was slightly less than 170,000. In addition there were passengers embarked and disembarked in Tilbury and other docks.

In Tilbury Docks the Authority had authorized the construction of a new quay on the north side of the main Dock. The quay would be 830 feet long with a return section 240 feet long. A "T"-shaped single-storey transit shed would be built, the main portion being 550 feet long and 120 feet wide. The shed was to accommodate passengers, as well as cargo traffic, and passenger platforms together with arrangements in the area for service buildings, railways, roads, and parking and other special facilities would be provided. A scheme for improved road access to the docks from the north had been planned in conjunction with other authorities concerned and would be undertaken when conditions permitted.

With regard to the main Tilbury entrance lock, some difficulty was experienced at certain states of the tide owing to the current which set across the line of the lock, but information given by Davis and MacKenzie amplified by Sir Cyril Kirkpatrick in a Paper [1] presented to the Institution required no qualification after about 30 years' experience. Considered today, the decision to place the entrance almost east and west from

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[1] F. W. D. Davis and W. MacKenzie, "Major Improvement-Works of the Port of London Authority, 1925–1930." Min. Proc. Instn Civ. Engrs, vol. 240 (1934–35), p. 258. See also *Discussion* by Sir Cyril Kirkpatrick, p. 325.

Northfleet Hope seemed to make the best possible provision, since ships arrived on the flood tide during which (and the subsequent slack water) the best conditions prevailed at the entrance. It might be that experiments which it would eventually be possible to undertake in the Authority's hydraulic model might indicate a simple way in which the ebb-tide current across the entrance could be reduced. However, unless the expenditure required to make that modification was small, it would not be worth while.

The docks had suffered practically no damage from the floods of January–February 1953 because the flood levels recommended by Sir George Humphrey and Sir Frederick Palmer in their report to the London County Council following the 1928 floods had been adopted.

In conclusion, the Author thanked those members who had taken part in the discussion. A great deal of work had been and was being done in London and other ports and he considered that the interchange of information regarding those works and the organizations developed to carry them out was one of a vital interest to the Maritime Division.

The closing date for Correspondence on the foregoing Paper has now passed without the receipt of any communication.—Sec. I.C.E.

RAILWAY ENGINEERING DIVISION MEETING

26 March, 1953

Mr J. C. L. Train, Member, Chairman of the Division, in the Chair

The following Paper was presented for discussion and, on the motion of the Chairman, the thanks of the Division were accorded to the Authors.

Railway Paper No. 49

"The Trend of Development in the Design and Equipment of Underground Railways"

by

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and

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Part 1.—A Review of Some Existing Systems by Mr Coombs

SYNOPSIS

Statistics are given of some of the world's underground electric railways and features of some new underground systems are described.

Technical matters reviewed include construction, alignment, and depth of tunnels, line capacity, schedule speeds, stations, track construction, and de-icing provisions.

Part 1 of the Paper ends with a review of recent or contemporary technical developments on a number of the world's underground electric railways.

Primary Statistics

Primary statistics of the established underground systems (Figs 1, Plate 1) mentioned in this review are set out in Table 1, whilst Table 2 sets out the systems in order of maximum passenger-carrying capacity with services actually operated.

Several of the systems listed in Table 2 have two or more types of stock with differing passenger-carrying capacities in operation. In each case the latest stock has been assumed to be the sole stock in operation. Real maximum traffic per hour is of course always below the gross-capacity

TABLE 1.—OPERATIONAL STATISTICS OF UNDERGROUND ELECTRIC RAILWAYS

City	Population aggregate: 1,000's (1)	Passengers per annum: millions (2)	Passengers per day: 1,000's (3)	Number of lines (4)	Route miles (5)	Car-miles per annum: millions (6)	Car-miles per route-mile: millions (7)	Originating passengers per car-mile (8)
New York	8,000	2,145	5,860	38	241·6	407	1·68	5·3
Paris	4,776	1,032	3,000	15	115·7	101	0·87	10·3
London	9,785	702*	2,000	6	223	225	1·01	3·1
Berlin	3,357	267	732	5	49·9	24·1	0·48	11·1
Philadelphia	2,680	182	621	4	25·1	19·8	0·79	9·2
Boston	1,500			3	58·5	12·0	0·21	
Chicago	5,000	153	504	2	28·6	43·5	1·52	3·5
Hamburg	1,700	156	426	5	41·5	18·2	0·44	8·6
Stockholm	753	80	219	2	15·5	6·0	0·39	13·4
Glasgow	1,090	37	100	1	6·6	3·0	0·46	12·3
Oslo	429	20	60	3	—	1·5	—	13·5
Rome	1,688	—	—	1	6·0	—	—	—

* Includes 79 millions from the main lines.

TABLE 2.—LINE CAPACITIES

City	Maximum trains per hour		Maximum cars per train	Maximum passenger capacity			
	Signalling capacity (1)	Actually run (2)	(3)	Seats per car (4)	Total car capacity (5)	Per train (6)	Per hour (7)
				No. %			
New York	40	32	10	54 18	300	3,000	96,000
London:							
Surface	40	38	8	40 17·6	227	1,754	61,200
Tube				40 22·6	177	1,416	53,900
Philadelphia (Broad St.)	30	30	6	67 28·6	234	1,404	42,140
Boston:							
Cambridge	35	26	4	72 25·9	278	1,112	28,900
Main	40	27	6	44 24·7	178	1,068	28,800
East Boston	40	22	4	48 26·7	180	720	15,840
Stockholm	40	24	8	52 34·7	150	1,200	28,800
Paris (articulated stock)	—	36	2 × 3	83 18·0	355	737	26,600
Hamburg	40	24	8	34 32·1	106	848	20,400
Chicago	40	25	8	51 51·0	100	800	20,000
Oslo	No signals	42	2	32 17·8	180	360	15,100
Berlin:							
small profile	40	18	8	30 33·3	90	720	12,960
large profile			5	35 29·2	120	600	10,800
Glasgow	—	20	2	42 52·5	80	160	3,200
Rome	—	—	8	48 24·0	200	1,600	—

figures listed in Table 2. In London, for instance, it is improbable that the traffic per hour ever exceeds about 30,000, or about 50 per cent of the ultimate passenger-capacity actually available over the maximum traffic hour.

A third method of comparing underground railway systems is by means of rolling stock performance.

In construing Table 3 it is necessary to remember that the values of station spacing are probably in some cases representative figures rather than accurate arithmetic averages for the system. So far as is known all schedule speeds relate to terminal-to-terminal runs.

Alignment

It is widely regarded as axiomatic that the main traffic flows in a city are radial rather than circumferential. This principle can easily be illustrated in London. But examination of the maps of some of the world's underground railways illustrates how considerably this conception has in fact to be modified to meet the physical geography of the town in which the railway is built. The system diagram for New York and that proposed for San Francisco also illustrate the difficulty of planning a line to carry simultaneously a two-way peak load which will overlap the city centre in two directions. This desirable means of improving the railway load factor to get two peak-loading runs on each peak-hour train is particularly difficult in a narrow isthmus or island. In a city free to grow in any direction, such as London, Paris, or Berlin, it is geographically easy so to design a railway, though lengthening of the lines makes the running of the same train with peak loads in both directions difficult or impossible. It may, however, be stated that there is a natural trend to build underground railways across a town rather than to an in-town terminal.

Stations

The spacing of stations is important for three reasons. It is expensive both to build and to operate closely spaced stations. The spacing of stations exercises a decisive influence on schedule speed and, therefore, largely determines the character of an underground railway. The spacing must be sufficient to impose an adequate but not too great a traffic on any one station.

The influence of station spacing on schedule speed is illustrated in *Fig. 2* and Table 4. It will be seen from *Fig. 2* that schedule speed increases broadly as a power function of the distance apart of the stations, within the economic and technical limits of power which are observed. Table 4 sets out some calculated figures showing the influence of station spacing, acceleration, deceleration, and maximum speed on schedule speed.

On the expense side, the power consumption of an urban-type railway

TABLE 3.—ROLLING STOCK PERFORMANCE

City	Energy per ton-mile: kWh. (1)	Energy per car-mile: kWh. (2)	Schedule speed: m.p.h. (3)	Accel.: ft/sec. per sec. (4)	Braking: ft/sec. per sec. (5)	Average spacing of stations: mile (6)	Balance speed: m.p.h. (7)
London							
Piccadilly	0·095*	3·1	23·4	2·2	3·8**	0·794	43–51†
Central		2·8	23·1	2·2	3·8**	0·947	43–51
Met.		3·2	22·47	3·0	3·8**	1·127	41–52
Boston							
Cambridge	0·123	5·9	21·59	3·66	5·86	0·692	36
Chicago							
Milwaukee Avenue	0·22	4·25	21·49	4·4	4·4	0·513	45
London							
Northern	0·095*	2·9	21·32	2·2	3·8**	0·664	43–51
Hamburg	0·115	2·37	21·1 outer	3·0	3·0	1·057	31
London							
Bakerloo	0·095*	3·6	20·73	2·2	3·8**	0·708	43–51
Chicago							
State Street		4·25	20·35	4·4	4·4	0·530	45
New York							
Express	0·100	4·82	20	3·0	4·4	2 to 4‡	50
London							
District	0·095*	3·1	19·77	3·0	3·8	0·626	41–52
Boston (*c*)							
E. Boston	0·202	5·0	19·10	3·66	5·86	0·543	47
Stockholm	0·17	6·0	19	3·23 to 5·66	3·23 to 3·66	0·435 City Centre 0·5 av. 0·567 Suburbs	44
New York							
Local	0·100	4·82	18 / 16	3·0	4·4	0·57 / 0·47	50
Philadelphia							
Broad St.		6·86	16·86	2·93	2·93	0·445	47
Market—Frankford		5·43	16·35	2·64	2·93	0·482	45
Boston (*b*)							
Main	0·135	4·8	16·55	3·66	5·86	0·517	38
Hamburg inner	0·115	2·37	16·0	3	3	0·473	31
Paris Max. V_s	0·110	3·547	15·75	Old 2·3 Artic'd 2·95	Old 2·88 Attic'd 3·28	0·324	Metro. 37·3
Berlin (large profile)	0·1075	"B" stock 2·5 "C" 3·5	15·38	1·97 / 2·30	2·46 / 2·46	0·487	33·6

TABLE 3—(*cont.*)

City	Energy per ton-mile : kWh. (1)	Energy per car-mile : kWh. (2)	Schedule speed : m.p.h. (3)	Accel. : ft./sec. per sec. (4)	Braking : ft./sec. per sec. (5)	Average spacing of stations : mile (6)	Balance speed : m.p.h. (7)
Glasgow . .	0·16	4·185	14·04	3·0	3·0	0·437	28·5
Paris . . .	0·110	3·547	12·6	Old 2·3	Old 2·88	0·324	Metro. 37·3
Min. V_s				Artic'd 2·95	Artic'd 3·28		
Rome . . .	—	—	—	3·28	4·92	0·62	—

* Average loaded ton-mile for all London Transport lines.
** Equivalent straight-line full service rate of braking.
† Higher figure is with shunt field.
‡ Spacing on express sections only.

is largely proportional to the frequency of stopping; the costs of station construction form a large proportion of total costs, and rolling stock requirements are largely dependent upon schedule speed in the general hypothetical case.

A double-ended station accommodating eight-car trains can cover, with end-sited stairs or escalators, nearly $\frac{1}{8}$ mile; it follows that double-ended stations can represent a large proportion of the distance-difference between two and three stations a mile. They have also, in the nature of things, a greater passenger capacity than single-ended stations. It is therefore interesting to note that all five of the in-town stations (Fig. 3, Plate 1, and Figs 4, Plate 2) on the portion of the Stockholm underground now in service are double-ended. It may be that this represents a progressive trend. It permits a higher schedule speed, economizes in power consumption, and yields construction economies, without missing important traffic objectives, gives enhanced uniformity of loading of trains, which makes for better braking, a quickened exit from the platform of arriving passengers, and a possible reduction of station-stop time through the improved distribution of alighting and boarding passengers. Double-ended stations are not unknown in London but they represent only a small proportion of the underground stations in service.

It is obviously undesirable from the point of view of the passenger to have deep stations. It is also expensive to take a passenger deep into the earth, and not conducive to securing his patronage for short-distance in-town trips. Why then have deep-level stations at all?

The answer generally depends on one or more of the following factors, which are, in practice, interrelated:—

(1) Avoidance of underground obstacles, such as the sometimes very deep basements of modern buildings, sewers, tunnels, piles, and services.

TABLE 4.—THEORETICAL RELATIONSHIP OF MEAN ACCELERATION/DECELERATION, STATION SPACING, S, SCHEDULE SPEED, V_s, AND MAXIMUM SPEED V

	$S = 0{\cdot}3$ mile			$S = 0{\cdot}5$ mile			$S = 0{\cdot}7$ mile			$S = 0{\cdot}9$ mile			$S = 1{\cdot}1$ mile		
f m.p.h./sec.	V_s m.p.h.	S_c miles	$\frac{dV_s}{dS}$ hours^{-1}	V_s m.p.h.	S_c miles	$\frac{dV_s}{dS}$ hours^{-1}	V_s m.p.h.	S_c miles	$\frac{dV_s}{dS}$ hours^{-1}	V_s m.p.h.	S_c miles	$\frac{dV_s}{dS}$ hours^{-1}	V_s m.p.h.	S_c miles	$\frac{dV_s}{dS}$ hours^{-1}
Maximum speed = 20 m.p.h.															
1	9·9	0·189	16·6	12·4	0·389	9·4	13·9	0·589	6·1	15·0	0·789	4·2	15·7	0·989	3·0
2	10·9	0·244	16·6	13·3	0·444	8·9	14·7	0·644	5·6	15·7	0·844	3·8	16·3	1·044	2·7
3	11·3	0·263	16·4	13·6	0·463	8·7	15·0	0·663	5·3	15·9	0·863	3·7	16·5	1·063	2·6
4	11·5	0·272	16·3	13·9	0·472	8·5	15·2	0·672	5·3	16·1	0·872	3·5	16·6	1·072	2·5
Maximum speed = 25 m.p.h.															
1	10·5	0·126	20·3	13·6	0·326	12·4	15·7	0·526	8·4	17·1	0·726	6·0	18·2	0·926	4·5
2	11·9	0·213	20·8	15·0	0·413	12·0	17·0	0·613	7·8	18·3	0·813	5·5	19·2	1·013	4·1
3	12·4	0·242	20·8	15·7	0·442	11·7	17·5	0·642	7·5	18·7	0·842	5·2	19·6	1·042	3·8
4	12·9	0·257	20·8	15·9	0·457	11·6	17·8	0·657	7·4	19·0	0·857	5·0	19·8	1·057	3·7
Maximum speed = 30 m.p.h.															
1	10·7	0·050	23·1	14·4	0·250	15·0	16·9	0·450	10·6	18·7	0·650	7·8	20·1	0·850	6·1
2	12·6	0·175	24·3	16·4	0·375	14·8	18·8	0·575	10·1	20·5	0·775	7·2	21·8	0·975	5·4
3	13·4	0·217	24·8	17·2	0·417	14·7	19·5	0·617	9·8	21·2	0·817	6·9	22·4	1·017	5·1
4	13·7	0·237	24·8	17·5	0·437	14·6	19·8	0·637	9·7	21·4	0·837	6·8	22·6	1·037	5·1

Maximum speed = 35 m.p.h.

1	—	—	—	14·8	0·160	17·0	17·8	0·360	12·6	20·0	0·560	9·6	21·7	0·760	7·5
2	13·0	0·130	27·2	17·3	0·330	17·4	20·2	0·530	12·2	22·3	0·730	9·0	23·8	0·930	6·9
3	13·9	0·187	28·0	18·3	0·387	17·5	21·3	0·587	11·9	23·3	0·787	8·7	24·8	0·987	6·6
4	14·5	0·215	28·3	18·9	0·415	17·4	21·8	0·615	11·8	23·8	0·815	8·6	25·2	1·015	6·4

Maximum speed = 40 m.p.h.

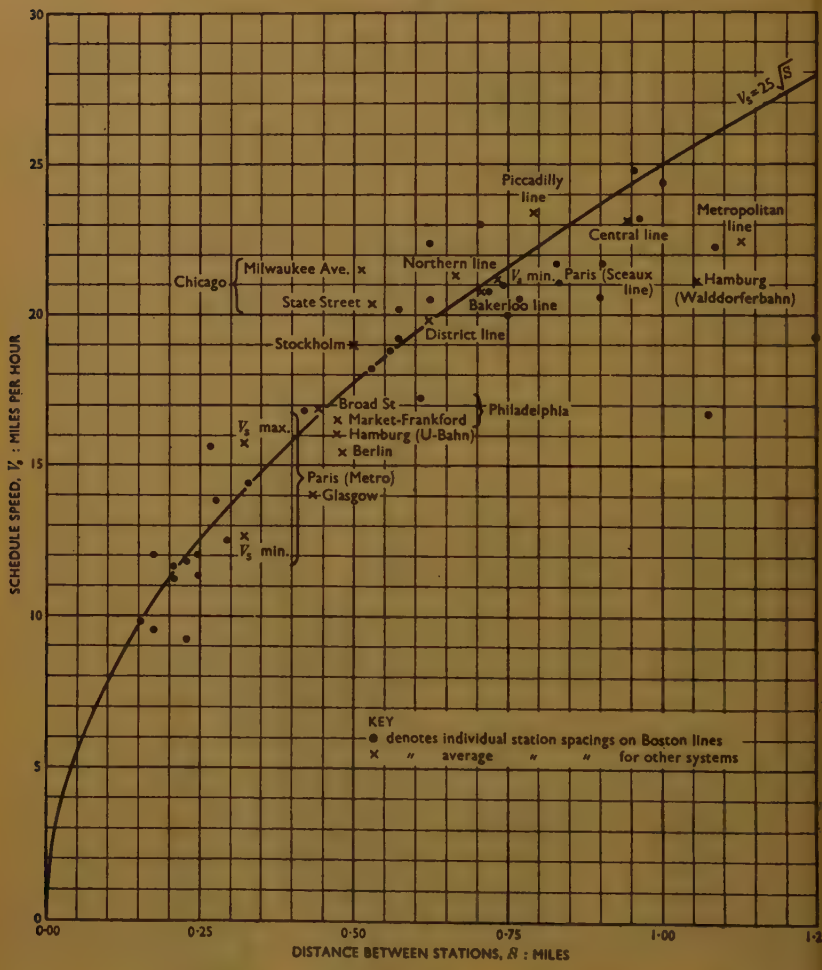
1	—	—	—	15·0	0·056	18·7	18·3	0·256	14·2	20·8	0·456	11·1	22·8	0·656	8·9
2	13·2	0·078	29·5	18·0	0·278	19·8	21·4	0·478	14·2	23·8	0·678	10·7	25·8	0·878	8·4
3	14·3	0·152	30·6	19·3	0·352	19·9	22·7	0·552	14·0	25·0	0·752	10·4	26·8	0·952	8·0
4	15·0	0·189	31·2	20·0	0·389	20·0	23·4	0·589	13·9	25·7	0·789	10·2	27·5	0·989	7·8

$t_s = 30$ seconds waiting time in station + 5 seconds running time = 35 seconds.
S denotes station spacing in miles.
V ,, maximum speed in miles per hour.
V_s ,, schedule speed in miles per hour.
S_c ,, coasting distance in miles.
f ,, acceleration and deceleration in miles per hour per sec.

$$\frac{dV_s}{dS} = \frac{3{,}600}{t} - \left(\frac{3{,}600}{t}\right)^2 \cdot \frac{S}{V} \text{ where } t = 3{,}600\,\frac{S}{V} + \frac{V}{f} + t_s .$$

$$S_c = S - \frac{V^2}{3{,}600f} \quad \text{and} \quad V_s = 3{,}600\,\frac{S}{t}$$

Fig. 2



RELATIONSHIP BETWEEN SCHEDULE SPEED AND STATION SPACING

(2) The width of public roads, which may be insufficient to permit cut-and-cover construction.

(3) The choice of a good tunnelling or trenching medium.

(4) Avoidance of direct point loads on the tunnel. This may involve tunnel strengthening.

(5) Observance of the minimum radius. Following the course of a public road at shallow depth may not be practicable if the road is too tortuous.

(6) A limiting positive grade as affecting the economic power-weight ratio of the rolling stock (see also 10).

(7) The relative total costs of cut-and-cover and tunnel construction, including (where appropriate) the costs of demolition, and cost of disturbance to street traffic and local community life.

(8) Avoidance of water troubles.

(9) Avoidance of underpinning difficulties.

(10) Securing minimum headway and maximum schedule speed. Long heavy ruling grades make for retarded acceleration climbing the grade and the imposition of speed restrictions running down the grade, or lengthened overlaps.

The steepening of the limiting grades gives greater freedom of design to railway planners both for cut-and-cover lines and for tunnel lines. It may be noted, however, that where underground railways are built along a sloping terrain the limiting grade may be practically coincident with the ruling grade. Thus, both in Toronto and Stockholm, substantial reduction of the limiting gradient would have meant deep-level stations and the substitution of tunnelling for cut-and-cover construction. In the case of Toronto it would also have created an almost impossible problem in finding a depot site.

On the Cockfosters extension of the Piccadilly Line, long lengths run at a gradient of the order of 1 in 60. In Toronto long lengths run at a gradient of about 1 in 30. In cases such as these both the limit of line capacity and schedule speed must be different for the up and down lines on account of the gradients into and out of stations. Moreover, where the line has a ruling grade substantially near the limiting grade it is not so practicable to put stations on humps, which is advantageous in saving power consumption, though it is fairly neutral in regard to the size of sub-stations. However, the placing of stations on humps is probably on balance slightly favourable to headway reduction for normal running, but adverse in the event of trains being halted at the outer home signal, within the limit that the headway on any line is determined by the minimum headway clearance of the worst station.

The placing of stations on humps is obviously more practicable with tunnelling construction than with cut-and-cover construction. It has been calculated that on the original length of the Central Line about 20 per cent saving in power consumption has accrued from putting stations on 10-foot-high humps.

Platforms

Colonel Bingham, head of the Board of Transportation of the City of New York, in his 1949 Report on the Transport Problem of San Francisco, in which he recommends the construction of a subway, states: "Island

platforms with a mezzanine are proposed for all stations where this type of construction is feasible, rather than side platforms without mezzanine. It has been demonstrated that the increased construction cost of this type of station is more than offset by savings in operating and maintenance costs. It also makes for greater convenience, and safety, by permitting easy access to trains in both directions without crossing the street."

This prescription has been observed in the Stockholm underground. The space between the converging tracks at the ends of the island platforms has been utilized for relay rooms, switch rooms, permanent-way cabins, and operating premises. In Toronto, however, although the mezzanine ticket hall has been proposed for a number of stations, side platforms are generally preferred. In Rome, three of the underground stations have a mezzanine ticket hall, but side platforms are generally adopted. The Rome administration, however, expresses a general preference for subsurface ticket halls.

Undertakings showing a preference for the subsurface "ticket hall" for underground stations are Berlin, Boston, Chicago, Philadelphia, New York, and Paris. Undertakings showing a preference for surface-level ticket halls are Hamburg and Glasgow.

In the new construction proposals contained in the London Plan Working Party's 1949 Report, advantage has been taken at every reasonable opportunity to provide cross-platform interchange between lines, including a reverse-running cross-platform exchange at Euston between the City branch of the Northern Line and Route C. In Stockholm a piece of four-track line under construction between Kungsgatan and Slussen is to have cross-platform interchange in both directions at Klara Station (Figs 5, Plate 2) which is being built on two levels. At the other two stations on this section the lines will run up-down-up-down on two island platforms. At Alvik Station there is cross-platform exchange between the underground trains and the Nockeby trains. On the projected San Francisco system one of five four-track stations is proposed to be built on two levels to avoid flat bifurcating junctions, the tracks being arranged up-up on one level and down-down on another level, thus giving cross-platform interchange.

There are, of course, arguments against the provision of cross-platform exchange. It makes both ticket control and passenger control at stations more difficult in some ways; on the other hand it is a valuable travel facility. It is to be noted that cross-platform interchange is not a feature of the Paris Metro although the system has a total of fifteen lines. On the whole it seems that cross-platform interchange is likely to become more and more a feature of new underground construction on systems operating several lines.

Recent underground constructions have been characterized by wider platforms, wider passages, wider stairways, higher ceilings, and bigger concourses than earlier underground stations. It may be concluded that greater spaciousness is a general trend in underground railway stations.

But greater spaciousness is expensive and economic factors may limit this trend. There appears also to be a marked trend toward siting station entrance stairs in property rather than on pavements in heavily built-up commercial areas.

Tunnels

Cast-iron-lined circular urban-railway tunnels appear to be mainly limited to London and Glasgow, although New York has some and Budapest has announced an intention to build a 16-foot-diameter deep tunnel line with part cast-iron and part concrete lining. Deep-level tunnels may or may not be more expensive to build than cut-and-cover constructions at particular locations. But, providing that easements can be obtained, deep-level tunnels are a much more flexible form of construction and may in fact be the only means of extending cut-and-cover subways to desirable traffic points ; they have been so built in New York.

On the eastern extension of the Central Line, London Transport has lined tube tunnels over a length of $2\frac{3}{4}$ miles with reinforced-concrete segments. In 1930 New York utilized reinforced-concrete-block circular tunnel-linings as a cheaper alternative to cast-iron-lined tunnels. The choice was determined by competitive alternative tenders. For 16-foot-6-inch-diameter tunnels there was a saving of 35 per cent using the concrete-block lining, although the cast-iron lining was to be finished with a further 4-inch lining of concrete. Since then, however, cast iron linings have been preferred.

Reinforced-concrete segments represent a considerable saving in cost over cast-iron segments, but it is possible that they may entail greater maintenance expenditure after a considerable period of service. It is also to be remembered that although London Transport uses an insulated return the steel reinforcement of the segments does represent a high resistance shunt path to the conductor rails which are respectively above and below earth potential. There is, therefore, the possibility in wet ground of electrolytic corrosion of the reinforcement causing spalling of the cover concrete ; no such reaction has, however, yet shown itself.

The trends in tube-tunnel construction are not easy to perceive. A composite reinforced-concrete and cast-iron segmental tunnel-lining is perhaps a likely formula where ground-water is not too active or too aggressive to concrete. This form of construction is difficult to design for a smooth internal face to the tunnel and for this reason reinforced-concrete-block construction may ultimately become more widely used for lining circular railway tunnels, though blocks, as contrasted with hollow segments, do involve extra excavation. They are also liable to settlement and cracking, and are not inherently very resistent to seepage. Since, however, the design of tube-tunnel linings is largely determined by the thrust pressures

of the driving shield, the design and production of a different type of tunnel-boring machine may permit the use of welded mild-steel linings at sites where corrosion hazards are within acceptable limits. Many soils are compressible and the future may see the development of a soil-compressing self-propelling earth mole, which, by decreasing substantially the spoil produced from tunnelling, may permit the much more rapid and cheaper construction of tube tunnels. Experiments are being carried out at the present time to devise a practicable method of eliminating the grouting of tunnel linings and if these endeavours are successful tunnelling work may be cheapened and quickened, at least marginally.

In cut-and-cover construction there appears to be a general trend towards the use of reinforced concrete. In Stockholm, much of the subway was constructed in the form of a reinforced-concrete rigid portal frame with a mass-concrete invert placed after excavation of the dumpling and sometimes reinforced with tie beams. Reinforced-concrete construction is also being used at Toronto and is currently favoured in the United States, Berlin, and elsewhere. It was also used for a short subsurface section on the eastern extension of London Transport's Central Line (*Figs 6* and *7*). In this connexion, the skilful use of reinforced concrete to aesthetic effect in a viaduct on the Stockholm system is illustrated in Figs 8, Plate 2, and *Fig. 9*.

Reinforced-concrete tunnel construction has the great advantage over mass-concrete or brick construction that it can have a sufficient inherent box strength to permit subway construction over ground of low and varying strength without the use of piles, which it may be impracticable to drive or to bore, for example in sand where settlement of adjacent buildings may be involved by pile-driving. It is also more immune from cracking caused by differential settlement of sections of the tunnel or from thermal movement of steel roof or stanchion sections, which means that in water-bearing soil the use of reinforced concrete in subway-tunnel construction is probably the only way to preserve the integrity of the waterproofing. In wet or low-strength-soil situations, reinforced-concrete construction seems likely to show an economic advantage in subsequent maintenance costs compared with either mass concrete or brick, or even compared with flat steel and concrete jack-arch roofing.

An incidental trend in subway construction is to provide all modern subways with inverts, in order to enhance the stability of the construction. Another such trend is to prescribe a minimum depth of cover greater than has been observed in the past. Many old subway tunnels in Europe and America were built to carry the road more or less directly on the tunnel roof. This arrangement economizes in the total excavation and backfill but raises the subsequent maintenance cost of the tunnels. Paris and Berlin regard a cover of a little more than 4 feet ($1\frac{1}{4}$ metre), New York, 6 feet, as the minimum, measured from the top of the tunnel to the road surface. This is one of the factors which probably has led to a growing

preference for mezzanine ticket halls. It is also widely accepted now that it is both technically and economically wise to design concrete or brick tunnels with sufficient clearance to take shuttering formwork for repairs to the tunnel interior.

Track

Most of the older urban railways appear to be conscious of the desirability of avoiding, in modern underground railway building, the small-radius curves which marked early constructions. The exceptionally low radii (see Table 5) of 1·6 chain (Philadelphia), 1·97 chain (Paris), 3·22 chains (Berlin), 3·7 chains (Hamburg), or 5 chains (London) are not likely to be repeated today. The recent constructions at Stockholm and Rome were built to the minimum of 10 chains. The eastern extension of the Central Line was laid out to the minimum radius of 18 chains. It may therefore be deduced that there is a marked trend to regard 10 chains or more as the minimum acceptable radius for modern construction, even where this means shallow-depth tunnels running under large buildings. (See Figs 10, Plate 2.)

Experience has shown that the high cost of maintenance of sharp curves, the practical necessity of limiting cant, and the consequent imposition of speed restrictions, together with the attendant increase in tractive resistance, make it worthwhile spending extra on initial construction to avoid sharp curves. A further relevant point is that the size of the tunnel must take account of centre-overhang and end-throw on curves. The presence on a circular-tunnel line of a sharp curve means either that the section on the straight must be built unnecessarily large or that the tunnel on the curve must be bored larger, in which case two sizes of shield are required, probably additional working shafts, and a further range of segments. With circular tunnels, therefore, it may actually cheapen construction to avoid sharp curves.

De-icing Measures

The icing hazard with ground conductors is met by one or more of the following expedients :—

(1) Use of side-contact or under-contact rails.
(2) Use of protective boards.
(3) Manual application of de-icing media.
(4) Deposition of de-icing media from track de-icing baths.
(5) Deposition of de-icing media from rolling stock.
(6) Mechanical removal of snow and ice :—
    (*a*) by manual scraping ;
    (*b*) by crusher wheels, blowers, scrapers, or brushes fitted to service or special rolling stock.

TABLE 5.—TRACK DETAILS

City	Gauge	Weight of rail: lb. per yard	Type	Pads	Min. radius: chains	Maintenance	Comments
Stockholm	—	82 87	F.B.	Rubber or woodfibre pads under rail and under baseplate. Block sleepers on concrete in tunnel	10	In traffic	Elastic spikes. 20″ of macadamized ballast over St Eriks bridge to minimize noise. 65′ 6″ rails are welded into 196′ 6″ lengths in open and into full length of track circuits in tunnels
Rome	1·43 m.	93·3	F.B.	None	10	—	—
Boston		85 100	T.	Resilient pads used between the plates and ties	1·14 loop 6·06 main	Minor repairs in traffic	—
Paris	1·44 m.	105	F.B.	No rubber or resilient pads	1·97	In some cases maintained in service	Rail joints staggered 2′ 4″ on straight and half rail-length on curves
Berlin	1·435 m.	90·5	F.B.	Poplar pads between rail and baseplate	Mainline 3·68 Sidings 2·48 (New works 10)	Partly in traffic: partly out of traffic	Vertical rails and cylindrical wheels
London	4′ 8½″	95	B.H.	Rubber used experimentally	12 20 desirable	Out of traffic	300′ welded rails in close-jointed half-mile lengths in open; in close-jointed track-circuit lengths in tube tunnel
Glasgow	4′ 0″	80		Not used	10	Out of traffic	—
Chicago	4′ 8½″	100	T.	Rubber pads on ties support the baseplates	5·15	In traffic	Welded rails in subway only

Hamburg	1·435 m.	74	F.B.	Poplar pads on ribbed plates	Running line 3·7 Siding 2·5	Out of traffic	Vertical rail and cylindrical wheels. Klochner-werke bi-metallic rails used on curves of 50 chains or less radius over last 20 years for both high and low rails
Philadelphia :							
Market–Frankford	5′ 2¼″	90	F.B.	—	1·6	In traffic	Rubber pads used on Delaware Bridge line. The difference in gauge prevents inter-working of the two systems
Broad-Ridge . .	4′ 8½″	100	F.B.	—	2·44		
New York . . .	4′ 8½″	100	F.B.	Rubber pads used but later removed. New design being considered	5·3	In traffic lines operated 24 hours a day	Mainly concreted track with ballasted junction work

Trends affecting the track appear to be :—

(1) Outside of tube tunnels, the maintenance of tracks during traffic.
(2) Increasing use of long welded rails.
(3) Increasing use of resilient pads.

TABLE 6.—DE-ICING MEASURES

Undertaking	Open route-miles	Volts	Current collection	De-icing provisions	Composition of de-icing medium	Protective boards
Berlin . .	10·5	750	Large profile : 3rd rail under contact Small profile : 3rd rail top contact	Large profile : None but protective boards Small profile : (i) Eight cars fitted with spring-loaded scrapers.* These trains are run as first trains in the morning	None used	Rail covered on top and at side Not fitted
				(ii) Oil is brushed on rail for 200 yards adjacent to station when cold weather predicted. This oil has a persistency of several days	$\frac{1}{3}$ old spindle oil (*spindelol*) $\frac{2}{3}$ petroleum	
				(iii) When rain falls on rails below freezing point and a continuous layer of ice is formed a powder is applied to melt the ice	90% calcium chloride kept in airtight containers	
Hamburg .	34·2	750	3rd rail, under contact	None used	None used	Rail covered on top and at side
Stockholm .	12	650	3rd rail, top contact	De-icing baths made to L.T.E. prototype and blower wagon	(i) Reducing sugars 44% ; sodium nitrate 17% ; other polyhydric materials 16% (ii) Similar Swedish fluid	Rail covered on top
London . .	90·1	630	3rd rail, top contact	(i) Sleet locomotives spraying de-icing fluid and fitted with ice-crushing wheels and steel brushes	(i) Glucose 15% ; dextrin-like materials 22·6% ; sodium chloride 18·1%	Not fitted
				(ii) De-icing baths dispensing a de-icing fluid	(ii) Glycerol 66·3% ; sodium nitrate 1·7% ; reducing sugars 6·1%	

Chicago . .	20	600	3rd rail, top contact	Sleet paste to prevent ice and snow formation is placed on conductor rail on inclines only, applied with long-handled brush	2 gallons ethylene glycol 20 lb. powdered graphite 10 quarts water	Not fitted
Boston . .	26·7	600	3rd rail, top contact	(i) Steel brushes attached to all cars (ii) Oiling devices on certain cars (iii) Ice cutters on certain cars	Transformer oil (Shell D1. ALA. 15)	
Paris . . .	17·1	600	3rd rail, top contact	(i) On inclines of 1 in 25, current rails heated by resistance cables (ii) Sleet train with snow brushes and air–oil spray	Mineral oil	Not fitted
Philadelphia	12·4	600	3rd rail, part top contact, part bottom contact on different lines	Sleet cutter used on top contact rail in open		
New York .	109·6	600 to 650	3rd rail, top contact	(i) De-icing fluid applied by train or manually by swab (ii) Electric rail heaters (iii) Additional third rail (iv) Steel brushes (see *Fig. 15*)	Alcohol	Rail covered on top with protective board on subway lines. Not fitted on elevated lines

The trends in de-icing top-contact conductor rails as revealed by similarity of practice are :—

(1) To use a de-icing fluid to attack snow and ice.
(2) To supplement (1) with means of physical removal of snow and, to a lesser extent, ice.

* See *Fig. 14.*

It should be noted that Stockholm utilizes a top-contact system for the first third-rail system in Sweden. De-icing baths are here used to give protection auxiliary to that afforded by side and top cover boards, and a blower-wagon clears snow from the current rail in order to prevent icing from the freezing of snow melted by the shoes.

Rail-Road Interchange

A minor but significant feature of urban railway station construction during the past two decades has been the endeavour to make provision for improving facilities of the rail-road interchange. So long ago as the early 1920's bus forecourts were provided on the Northern Line, and in 1932 at Manor House covered islands for tram passengers with stairwells to the ticket hall were provided. The latest such provision in London is the Newbury Park Bus Station (*Fig. 11*).

In Toronto, on the Yonge Street subway, special provision is being made at six stations for covered street-car or bus-interchange platforms or other similar facilities.

The proposals for San Francisco specify that the subway stations should be designed so that transfer from one transportation medium to another should be simple and sheltered.

It seems likely that construction of special accommodation for road-rail interchange represents a trend which will develop in the future into more general provisions than have yet been supplied, but this development as an amenity provision is clearly dependent upon prevailing economic conditions.

Ventilation

In London, forced ventilation is not found to be necessary for sub-surface tunnels, but is extensively employed on the tube system. It is not apparently needed much in most other underground systems.

Berlin, Hamburg, Glasgow, Philadelphia, and Rome have no forced ventilation plant for tunnels. In Boston, fans are installed at various locations, but it has not there been found necessary to use forced ventilation. Similarly, in Chicago, fans are used only for emergency and to supplement the piston action of trains in the downtown station area, and in New York blowers are used at each end of the under-river tunnels. In Paris, pressure fans are installed, the air being exhausted through station shafts; this is the reverse arrangement to the practice in London of installing exhaust fans to draw in air through station entrances.

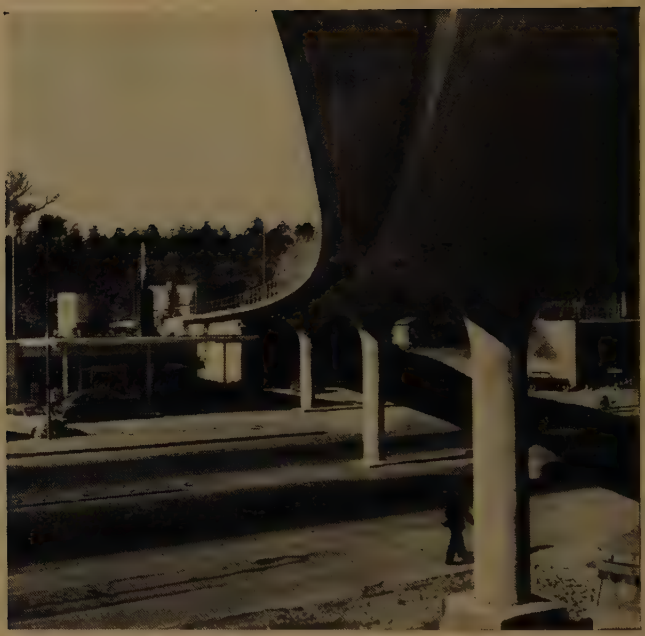
In Stockholm, on the tunnel sections so far built, ventilation shafts are installed, one midway between stations, and one at each end of the station; but of thirteen shafts so far installed only two have been equipped with fans. At the shafts not fitted with fans it is hoped that the motion of the trains will bring about adequate ventilation though, if necessary, fans will

Fig. 6

Fig. 7

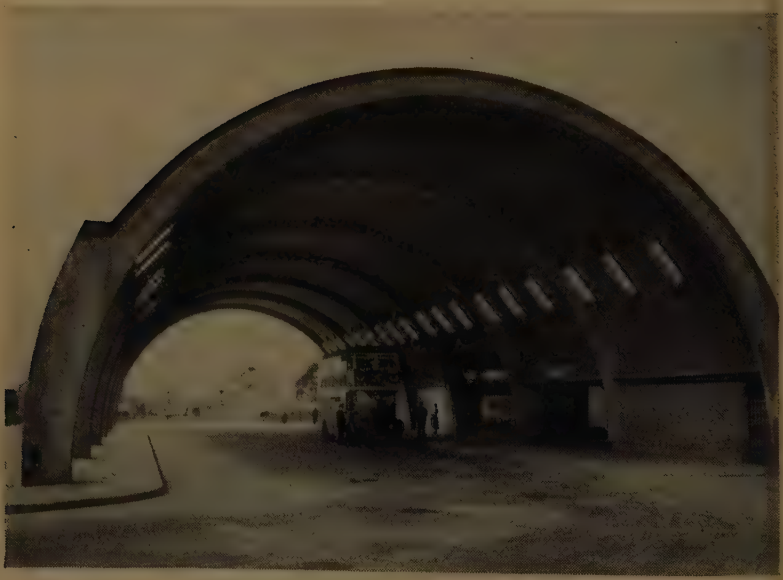
EXAMPLES OF THE USE OF REINFORCED CONCRETE ON THE CENTRAL LINE OF LONDON TRANSPORT

Fig. 9



A Viaduct on the Stockholm System

Fig. 11

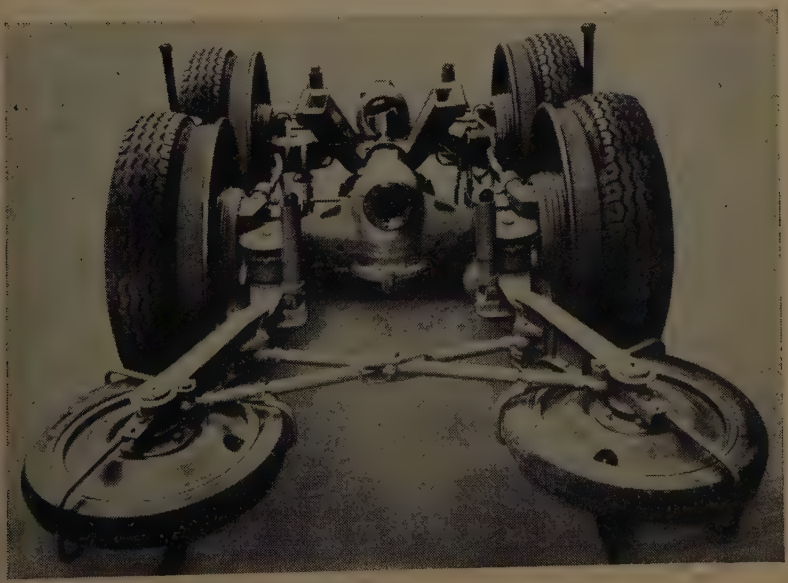


Newbury Park Bus Station

Fig. 12

PARIS METRO.—PROTOTYPE MOTOR-CAR WITH PNEUMATIC TIRES

Fig. 13



THE BOGIE OF THE CAR ILLUSTRATED ABOVE

Fig. 14

Berlin Underground—Ice Scraper

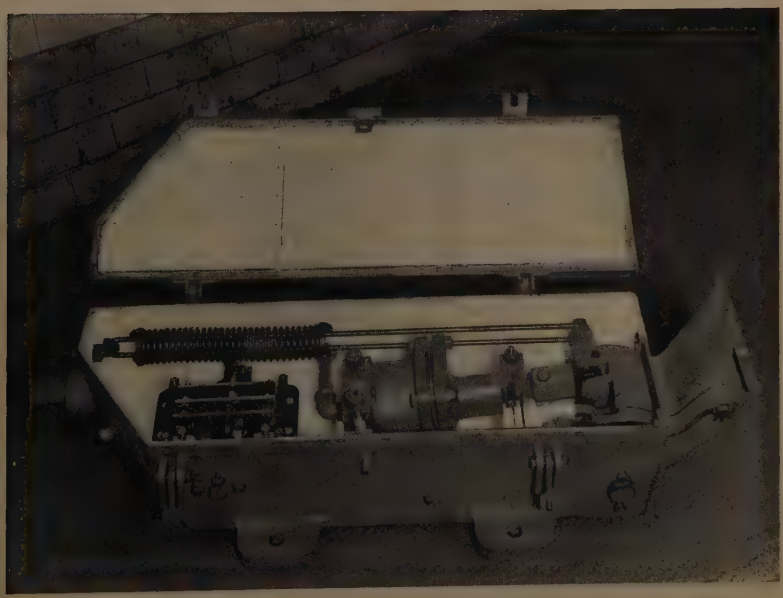
Fig. 15

New York Underground—Snow Brush

Fig. 17

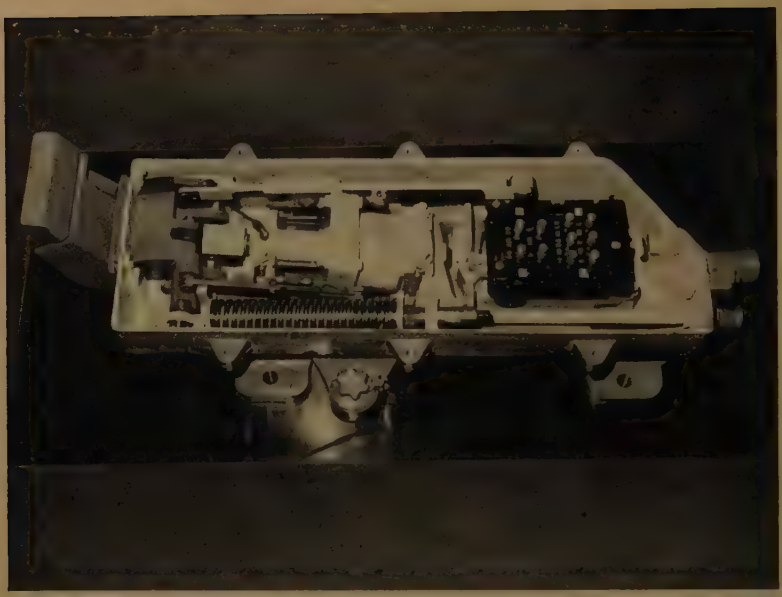
OLD PATTERN TRAINSTOP

Fig. 18



ENCLOSED-TYPE TRAINSTOP

Fig. 21



TRAINSTOP WITH FORCED OIL LUBRICATION

Fig. 22

TEN-CORE SCREENED CABLE

Fig. 23

THREE-CORE SCREENED CABLE

Fig. 24

HARROW-ON-THE-HILL MAIN SIGNAL CABIN INTERIOR

Fig. 25

HARROW-ON-THE-HILL MAIN SIGNAL CABIN RELAY ROOM

Fig. 26

EALING BROADWAY SIGNAL CABIN INTERIOR

be built in. The full ventilation principle proposed for Stockholm is reversed in summer from its winter circuit. In summer-time, the fan midway between stations extracts 118,000 cubic feet per minute whilst the fans beside adjacent stations inject 41,000 cubic feet per minute, leaving 18,000 cubic feet per minute to drift in through each station in each direction. In winter the midway fan injects 88,000 cubic feet per minute and the fans beside the adjacent stations extract 59,000 cubic feet per minute, leaving 15,000 cubic feet per minute to drift in through each station in each direction.

In London two general circuits are used. Where stations are closely spaced it is considered appropriate to extract air from the running tunnel immediately before the station. In this situation most of the air exhausted travels along in front of the approaching train from the previous station. The short path between a station entrance and the extraction point adjacent to it does not have much airflow. With this arrangement the shaft between stations, where it exists, serves to afford slight draught relief. Where stations are widely spaced it seems on balance advantageous to have the exhaust fan installed at a shaft situated midway between stations, the shafts adjacent to stations or in the stations and not used by the public being utilized as draught-relief shafts.

London tube fans are worked on the same circuit and at the maximum capacity in summer and winter alike, not because the air vitiation in the tubes demands it, for it does not, but because extraction of the heat generated by electric traction operation in the tunnels tends to raise the temperature to a point beyond what is comfortable to the travelling public and because little heat can be extracted by ventilation in summer. This heat-removal problem is a very difficult one.

The Paris Metro Pneumatic-Tired Train

On the 13th April, 1952, a prototype motor-car (*Figs 12* and *13*) with pneumatic tires was put into service on a half-mile test length of tunnel in Paris.

The primary advantages claimed for this form of traction compared to orthodox trains are :—

(1) Softer and more silent running.
(2) Saving of weight per vehicle.
(3) Improved adhesion.
(4) Cheaper vehicle construction.
(5) Cheaper track construction and lessened track maintenance costs.

The derived advantages claimed are higher possible rates of acceleration and deceleration resulting from (2) and (3) above, with consequent greater line-capacity and schedule speed.

Mr Ruhlman, General Engineer of the Paris Transport System, has

stated that the power consumption per ton-mile of the pneumatic-tired vehicle running on the Paris Metro would be 10 per cent greater than that of the orthodox car, but since the pneumatic-tired vehicle has 40 per cent less weight, an approximate saving in power per car-mile of 30 per cent is possible.

It is to be noted that the additional power per ton-mile is partly a function of the reciprocal of the station spacing. The average station spacing on the Paris Metro is 0·324 mile, and is probably the lowest of any underground railway system in the world save that of Barcelona with a spacing of 0·257 mile on its existing system, although the planned extensions of the Barcelona system are to have the stations spaced at 0·358 mile. It therefore follows that the additional power per ton-mile for pneumatic tires will be less on the Paris system than on other systems.

The reduction of power per car-mile is obtained by reducing the weight of the vehicle, and whilst the pneumatic-tired bogie no doubt has inherent possibilities of weight reduction which the traditional bogie does not possess, it is not the only approach to the vehicle-weight-reduction problem.

The Paris administration has, concurrently with the pneumatic-tired-vehicle experiment, produced a new three-car articulated unit on four bogies, two of which are motor-driven ; a train of two such units, each of three cars, is about the same length as the existing five-car train it is intended to supersede. The articulated train is only 77 per cent of the weight of the train it will replace.

London Transport has tackled the weight reduction problem by the use of aluminium alloy bodies and underframes and by that means has reduced body weights by 30 per cent and overall car weights by 16 per cent.

In emergency, the pneumatic-tired stock can stop with a deceleration up to about 10 feet per second per second under dry conditions, and this is clearly higher than what is practicable with steel-tired stock braking on wheels alone. However, Mr Ruhlman takes the view that 4·6 feet per second per second is about as much as should be imposed upon standing passengers and that normal rates of acceleration or deceleration should not exceed a value of that order ; though it is possibly more true to say that standing passengers ought not to be exposed to a rate of change of acceleration of more than about 2 feet per second per second in a second.

However, so far as acceleration is concerned, Chicago with all axles motored apparently achieves 4·4 feet per second per second, more than what is to be obtained from the Paris pneumatic-tired train. So far as deceleration is concerned, Boston stock is reported as reaching 5·86 feet per second per second with rheostatic braking allied to individual-wheel pneumatic-cylinder-actuated tread-brakes and pressure control. The new stock at Rome is to have a braking rate of 4·92 feet per second per second, achieved by rheostatic, electro-pneumatic, and magnetic track-brakes in

combination. It may be deduced, therefore, that traditional stock can accelerate and brake at the maximum rates which it has been suggested standing passengers can endure without instability. If that is the case then so far as normal running is concerned it is doubtful whether the practicable ceiling of acceleration and braking is raised by the use of pneumatic tires. But owing to its higher emergency braking rate pneumatic-tired stock can undoubtedly raise line capacity above what is practicable with steel-tired stock without magnetic track brakes, which may, however, become more general with the wider use of dynamic braking; though it is likely that extended use of track brakes will be resisted by track engineers.

It is also claimed for the pneumatic-tired train that it makes possible the construction of underground lines with 1-in-7 grades, thus avoiding deep stations, where orthodox traction is limited to running up 1-in-25 grades. The last part of this statement is a practical truth rather than an inescapable limit. With half the axles motored, two-car units on the Glasgow system climb a maximum gradient of 1 in 16, so that adhesion alone does not necessarily limit the maximum gradient installed to 1 in 25. Philadelphia, Hamburg, and Boston all have maximum gradients of 1 in 20.

In general, it seems more likely that factors other than adhesion will limit the gradient which is acceptable on an underground railway. The economic use of power is one such factor. If the gradient to be climbed needs more power than is otherwise worth while, it then becomes a matter of economic balance to adjust the power to be installed to the maximum gradient to be employed.

So far as softer and more silent running is concerned, although the pneumatic tire probably has greater potentialities than any other alternatives, resilient wheels also have possibilities in this direction and are being used or will be used experimentally in Rome, New York, Chicago, and Paris. And the tendency to increased use of rubber in bogie construction may also contribute to lower the noise level and enhance the smoothness of underground travel in traditional railway vehicles.

The remaining claims for the pneumatic-tired car are that it is about 10 per cent cheaper to build than an ordinary railway car, owing to saving in weight and the employment of standard gear-axle units from the heavy vehicle industry, and that it is possible by its use to save in track construction and maintenance costs.

So far, the pneumatic-tired train has been envisaged for running under cover. It may be that in the open some of the advantages which the train undoubtedly possesses in tunnel would be qualified.

In this connexion, the Paris pneumatic-tired bogie is guided when running on plain track by horizontal wheels which bear against the feet of flat-bottomed rails lying on their sides. (See *Fig. 13.*) This side guidance obviously cannot be continued through crossing work and here the bogies

are guided by the flanges of the steel tires. It may be that there is a possibility of a heavy fall of snow compacting under the rubber wheel sufficiently to lift the steel flange clear of the guiding rail head, owing to the large contact area of the pneumatic wheel. Similarly there is the possibility of snow and ice not being extruded from the ribbon track so that adhesion of the rubber wheel on compacted snow or ice may actually be less than that of a steel wheel on a wet steel rail.

Costs

Costs of underground railways vary widely and cannot be closely compared without analysis of the cost make-up. Pre-war tube-line costs in Britain were of the order of $\frac{1}{2}$–$\frac{3}{4}$ million pounds per route mile including all equipment, buildings, lands, etc. Present tube-construction costs are likely to be of the order of $1\frac{1}{2}$–$2\frac{1}{2}$ million pounds per route mile. Costs of underground railway construction abroad appear to come within this range, although 1949 estimates for an underground system in San Francisco were of the order of 10 million dollars per route mile inclusive of rolling stock. This cost, however, has been contrasted with the cost of building Wacker Drive in Chicago (22 million dollars per mile exclusive of the loss of revenue from taxable properties) and with the cost in New York of widening Varick Street and extending Seventh Avenue, of 6 million dollars per mile.

The financial aspects of underground railways are most properly assessed by non-philanthropic welfare economics, in which real costs are distinguished from money costs.

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Part 2.—Signalling
by Mr Willson

SYNOPSIS

After a brief reference to the principal points of divergence between main line and underground railway practice, attention is drawn to the rapid growth of passenger delay arising from the failure of equipment.

The importance of reliability in signalling apparatus is stressed, and statistics are quoted to illustrate the present standard obtaining.

The overhaul and maintenance problem has been tackled by organization and modifications to design, the controlling factors of which are illustrated by reference to the design of trainstops and relays.

Until recently the standard signalling cable was of the lead-covered two-core or single-core type, but the influence of changing costs of raw materials and advances in cable manufacturing techniques have brought about the production of a screened multicore cable suitable for use on underground-railway signalling installations.

Signal cabin and apparatus accommodation are mentioned and illustrated.

Changes in the signalling techniques as a result of the ever-growing demand for more frequent trains are discussed in relation to the control by the signalman.

Reference is made to changes in installation methods in order to compensate for the shortage of suitable skilled labour.

Introduction

The trend of signalling development on the underground railways of London has been moulded by four principal factors in which underground railway practice differs from that of the main-line railways, namely :—

(*a*) Train interval.
(*b*) Accessibility of signalling apparatus during traffic.
(*c*) Rolling stock characteristics of performance.
(*d*) Class of traffic.

The problem of providing an adequate signalling system is simplified on the London underground railways by the fact that traffic is only of one class (passenger), and the characteristics of trains on the same line are substantially similar ; the train interval is, however, considerably shorter than that required on any main-line service, and apparatus in the tube tunnels is inaccessible while trains are running, so that delays will be avoided only in so far as the signalling apparatus is of a standard approaching absolute reliability.

Apart from the financial cost of delay, a failure may impair safety by the introduction of the human element, for under normal conditions the human element is almost eliminated in the passage of the train from one end of its journey to the other ; indeed, if a signal is disobeyed the train is automatically brought to a standstill by the trainstop device, and protection from collisions at junctions or termini is afforded by the complete interlocking of levers, points, and signal circuits.

Existing Equipment
(See Table 7)

The whole of the system is equipped with track circuits which form the main controlling function and on which the safety of the train is entirely dependent. The position of a train is detected by the de-energization of a relay brought about by the wheels and axles of the train connecting together the two running rails. The traction system uses two conductor rails and therefore leaves the running rails free for signalling purposes.

Table 7.—Signalling equipment in service at 31st December, 1951
(London Transport Executive)

Signals, colour light	4,405
„ electro-pneumatic	999
„ electric-motor-driven	23
„ wire pulled	217
Trainstops	2,997
Pairs of points	1,623
Track circuits	5,639
Insulated rail joints	11,568
Working levers	3,515
Point heaters	394
Total	31,380
Signal cabins	140

Compressed air at 60 lb. per square inch is the main source of mechanical power, controlled by electro-pneumatic valves local to equipment.[1]

Present Reliability of Apparatus

The degree of reliability which has been reached is shown in *Fig. 16*, and for the purpose of reducing failures by the re-design of equipment and other preventive measures, every failure is recorded and analysed.

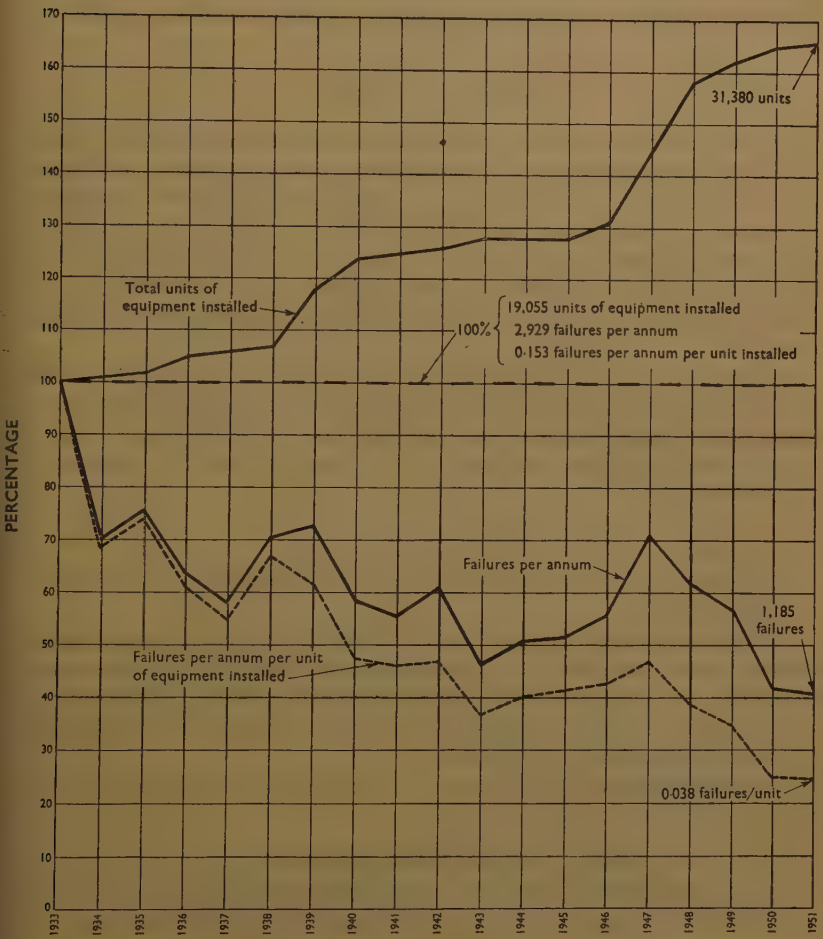
Routine Changing of Apparatus

All equipment having components subjected to movement and wear is replaced every 5 years, this having been taken as a reasonable expectation of failure-free life subject to proper maintenance. Excluding rail insulation joints there are 50,000 such items calling for an overhaul rate of 192 items a week.

The changing is carried out during the average night of 4 non-traffic hours by a staff of eighteen men under the supervision of an Inspector, who is responsible for the testing of the equipment before traffic is resumed the following morning.

[1] The references are given on p. 641.

Fig. 16



UNITS INSTALLED, FAILURES, AND FAILURES PER UNIT

(Note.—1 unit = 1 signal, trainstop, pair of points, track circuit, insulated rail joint, or working lever.)

In order to co-ordinate the changing and overhaul programme and provide a balanced quantity of apparatus types, and at the same time to ensure that no apparatus is missed, control is effected by a card system operated from the Drawing Office. There is one card for each unit of equipment, and monthly quotas are issued advising the overhaul-shop and changing-squads of their programme.

By this method, the float of apparatus necessary as a buffer between

immediate demand and steady overhaul shop production is retained at the minimum, and the corresponding locked-up capital is held at a low level.

Design of Apparatus

Apart from the provision that there must be no possibility of a failure which will introduce dangerous conditions, it is clear that reliability in service must be a major factor of influence in the design of signalling apparatus. Other factors are standardization to reduce the number of kinds of equipment performing the same function, interchangeability, simplicity, reduction of moving parts, enclosure in a weather-proof and dust-free atmosphere, and the facility for rapid replacement of complete units.

Subordinate to these main factors are a possible shortage of skilled labour to give full attention to equipment in service, and the very short maintenance period between the close and start of traffic each night, in consequence of which maintenance on site is being replaced by overhaul in the workshop.

The Trainstop

An example of these combined forces at work is shown in the evolution of the trainstop.

This is a safety device which, in the event of a train passing a signal at danger, applies the brakes on the train automatically and independently of the driver. The raised trip arm 3 inches above the top of the running rail engages with a brake-valve lever mounted between the leading shoe beam and truck chassis of the train.

The early pattern of trainstop was basically simple, as shown in *Fig. 17*. It consisted of three coupled units :—

(*a*) An arm and drive shaft pivoted in bearings.
(*b*) A compressed-air piston-motor and return-spring assembly.
(*c*) A detection box which proved that the arm had returned to the raised position after the passage of each train.

Disadvantages of the design lay in the number of sleepers covered by the combined assembly, which raised difficulties in connexion with the proper maintenance of the permanent way ; the relative movement of the sleepers under the stresses set up by passing trains produced wear of bearings, links, and pins, and it was essential that regular attention should be given to lubrication.

Temporary removal for site work also included complete dismantling, re-assembly, and adjustment before traffic could be resumed.

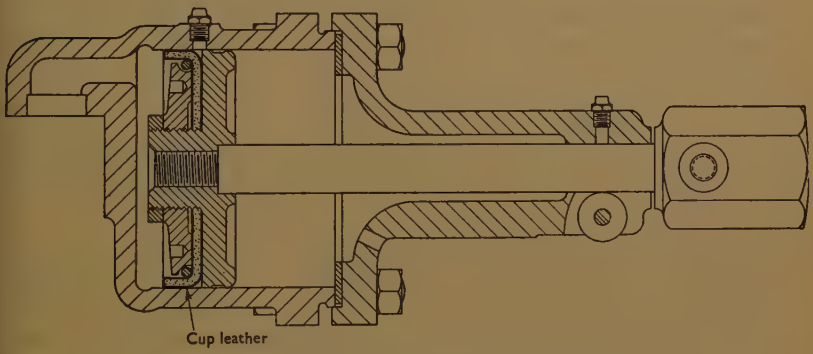
The next stage of development was the total enclosure of the mechanism, as shown in *Fig. 18*.

The piston sealing shown in *Fig. 19* is of leather and, although in general

use for many years, an occasional breakdown allows air to escape, leaving insufficient power to operate the trainstop. Bronze piston rings are now used, with an end seal of rubber as shown in *Fig. 20.*

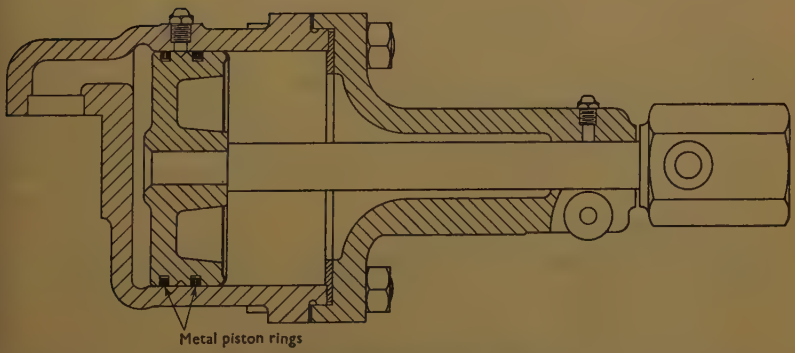
Long and reliable service depends upon regular and proper lubrication

Fig. 19



TRAINSTOP CYLINDER, LEATHER PACKED

Fig. 20



TRAINSTOP CYLINDER, METAL PACKED, WITH RUBBER SEAL AT JOINT BETWEEN BODY COMPONENTS

and cleaning, and in this respect dependence was still placed on the human element.

Many parts of the railway were equipped with all-electric trainstops but their inherent complexity and many moving components resulted in the need for considerably more maintenance than that required for the electro-pneumatic counterpart; consequently, as each section of line has been modernized, the compressed-air supply has been extended and the electric trainstops displaced.

Failures have shown the need for a further improved design and a new specification was introduced calling for a failure-free life of 5 years without maintenance. The prototype of the new design performed two million operations without failure.

The latest model, shown in *Fig. 21*, incorporates a piston pump actuated from a cam on the main shaft, which ejects a small quantity of oil through a number of jets strategically placed to lubricate all moving joints and sliding surfaces. The oil drains back to a sump from which it is filtered and re-circulated.

Relays

The relay plays possibly a more important role than any other single piece of signalling apparatus, for the safety of the system is dependent upon its correct functioning.

There are 21,800 relays in service on the London Transport railways, the greater portion energized by alternating current.

During 1951, there were fourteen relay faults and since each relay operates approximately 150,000 times in 1 year, this amounts to one relay failure to 234 million successful operations.

The principal improvements have been in the modifications to the vane, producing a more efficient operation, and the required contact pressures for wide variations of applied voltage.[2]

A detachable terminal panel on top permits a relay to be changed quickly without the risk of wrong re-connexion.

The maintenance of relays is carried out in the Signal Overhaul Shop and owing to the standardization of the basic elements of the fifteen types of relay in general use, it has been found economical to apply production line techniques; this method of overhaul has proved most advantageous from the increase of overhaul capacity, with existing skilled staff reinforced by unskilled labour.

Advantage is taken of the complete dismantling and re-assembly to standardize all components.

The assembly line is supplied with components and sub-assemblies manufactured in bulk in other parts of the shop.

Cables

It is the policy of London Transport for all wiring of signal circuits in cables at the side of the track to be so arranged that, in the event of the insulation of any wire breaking down, it will not be possible for extraneous current to energize a circuit and lead to the false clearing of a signal.[2]

The standard lead-covered cable adopted for signalling circuits has two cores or a single core of 0·064-inch-diameter single-strand tinned copper wire insulated with a rubber compound.

Signal circuit supplies are single-phase alternating current at 100 volts, 33⅓ cycles per second, transformed down from a 600-volt signal main.

Since its introduction in 1905, the lead sheath has been greatly improved ; the early sheath was of almost pure lead, 0·045 inch thick, which was very malleable when new, and suitable for handling without damage, but with age and subjection to vibration the lead became brittle and the formation of cracks allowed water to infiltrate.

An increase in the thickness of the sheath to 0·06 inch and the addition of 3 per cent of tin produced a reliable alloy, further improved in the present lead alloy containing cadmium and antimony.

The above policy has hitherto prevented the use of multicore cables for signalling circuits, but recently ten-core and three-core screened cables of a new type have been introduced, with a view to providing a cheaper cable and reducing the cost of installation without in any way reducing the safety of the signalling.

Ten-Core Cable

In *Fig. 22* it will be seen that each conductor is a single strand of 0·064-inch-diameter tinned copper wire insulated with rubber compound to 0·116 inch diameter for 660-volt pressure.

Surrounding this is a treble-lapped layer of $\frac{5}{16}$-inch-by-0·006-inch tinned copper tape applied edge to edge and in opposite directions forming a continuous screen. The ten screened wires lie on a rubber core approximately $\frac{1}{2}$ inch in diameter. One of the cores has one anodized aluminium tape dyed red as a marker.

Surrounding the whole is a longitudinally ribbed sheath of " Neoprene."

The manufacturer supplies the cable in lengths which are multiples of 25 feet or 36 feet, from which the London Transport Signal Overhaul Shop manufactures it into finished units, the ends of which are moulded with gland castings and a numbered vulcanized web serving to identify and locate each wire end.

The ten-core cable was designed for the special purpose of improving the method of connexion between apparatus on the track and the cables in the cable run, a section which from experience of failures has proved to be a weak link.

It is designed to withstand mechanical damage by blows from the tools of track workers or from heavy objects dropped on to it.

The cable-run end of the cable is connected to a terminal box mounted on the cable run.

The past practice was to install reinforced-concrete troughing in which the lead-covered cables were carried between the cable run and the apparatus connected to the sleepers. Such a method was costly in maintenance, for damage frequently occurred through heavy objects being dragged over it, and where covers became displaced sharp fragments of ballast falling in became wedged and under the influence of vibration punctured the sheath, allowing water to enter.

The presence of the troughing between timbers restricted the proper

packing of the permanent way, and where it was necessary to carry out track lifting or slewing as a result of embankment settlement it was also necessary to bear the cost of renewing the troughing.

The multicore cable rests on the track ballast without supports and may be moved aside for access to sleepers for packing or lifting.

A ribbed Neoprene sheath, similar to that protecting the ten-core cable, has also been experimentally applied to 600-volt cables of 1·5-square-inch copper cross-section for traction-rail connexions. The experiment so far is proving satisfactory, and it is expected that this will supersede the use of timber or asbestos troughing which is in general use today for the protection of the existing " Brumite " and braided traction cable.

Three-Core Screened Cable

The use of multicore cables has the advantage of cheapness since so many circuits can be enclosed in the same lead sheath, which is the most costly component of the cable. However, if too many circuits are included in a single cable a disadvantage is introduced in the need for special housings for disconnexion points, where the circuits branch to their various functions. The three-core screened cable has therefore been selected as sufficient to cater for all the controls and indication circuits necessary between the signal cabin and a signal or a set of points.

From *Fig. 23* it will be seen that each of the three 0·064-inch-diameter tinned copper wires is insulated by a layer of Brumite for 600-volt insulation on which is lapped a double layer of tinned copper tape, the cross-section of which is at least equal to that of the central conductor.

A layer of polyvinyl chloride for 250-volt insulation surrounds each screen separating the screens of each core from each other.

The interspaces are filled with Brumite compound and surrounding the whole is a lapping of non-hygroscopic varnish-impregnated linen tape and a lead sheath to provide mechanical strength.

Compared with the circuit equivalent of three lead-covered two-core cables, the three-core screened cable shows a considerable saving of installation labour and cable-run accommodation.

The cost of manufacture is 27 per cent cheaper and it is expected that following the experimental stage there will be further reductions in manufacturing costs as the many technical and production difficulties are overcome.

Experiments are proceeding with a view to the use of a braided screen of 36-S.W.G. tinned copper wires in place of the lapped copper strips.

The saving in raw materials is seen from Table 8.

Design of Signal Cabins and Apparatus Accommodation on Tube Railways

The primary factors which influence the design of apparatus accommodation on tube railways are :—

(*a*) Reduction of fire risk, by the sole use of non-inflammable materials.
(*b*) The desirability for easy access to apparatus at all times.
(*c*) The relatively high cost of space.

TABLE 8.—COMPARISON BY WEIGHT OF CABLES FOR EQUAL CIRCUIT CAPACITY (LONDON TRANSPORT EXECUTIVE)

(1) 0·064-inch three-core screened and lead-covered signalling cable.
(2) 0·064-inch two-core lead-covered signalling cable.
(3) 0·064-inch single-core lead-covered signalling cable.

Material	Weight: lb. per yard		
	One three-core screened cable	Three two-core cables	Six single-core cables
Lead	2·72	5·46	4·08
Copper	0·42	0·23	0·22
Insulation . . .	0·24	0·25	0·25
Filling	0·29	0·59	—
Total . . .	3·67	6·53	4·55

In the tunnels, relays are housed in specially designed cast-iron relay-cases bolted between the ribs of tunnel segments within a few inches of passing trains and totally inaccessible during traffic, but near to stations the additional cost of cable is considered a worthwhile investment to bring the relays into rooms constructed on the ends of station platforms.

The advantages of such an arrangement are that, with the improved accessibility, failures may be quickly located with the minimum of delay to trains, and often are avoided by observation.

It is very rarely practical on tube lines to construct a signal cabin within direct view of the trains, so that the signalman has to rely upon electrical indications provided on an illuminated diagram suspended above the lever frame. The position of trains and the aspects displayed by signals are shown in diagrammatic form whilst the " train describer " and telephone supply any other necessary information.

Earlier power signal cabins comprised two units, the signal cabin proper with the power frame and ancillary equipment, and the relay room or cabinets separately accommodated nearby. Timber was used quite freely in floor and cabinet construction, and access to the locking frame, contacts, locks, and wiring was restricted. Twenty years ago, the use of timber was eliminated and in 1945 a design of cabin was introduced in which the signal cabin and apparatus room were sections of a single room having a steel partition dividing the two.

The locking frame was installed with only the levers and forepart of the frame within the signal cabin section whilst the rest of the frame, including circuit controlling contacts, electric locks, and wiring protruded into the relay room section.

The illuminated diagram and telephone panel were similarly built into the partition. A later modification to design included raising the floor of the signal cabin above that of the relay room, in order to provide easy access beneath that part of the power frame within the relay room section.

The Relation of Signalman to Traffic

The block signalling methods of early tube railways became uneconomic with the increases of train service, owing to the large number of additional signalmen and signal cabins required, and the problem was resolved by the evolution of automatic signalling, which permitted a reduction in the number of signal cabins, retaining only those at intermediate reversing points, junctions, and terminals.

At junctions and terminals, the increasing service density was reflected in the need for sustained concentration, and efforts were made to reduce this factor of the signalman's duty by the introduction of route signalling.

By this system one lever movement brings about the movement of all points and the clearing of signals for the passage of a train from one part of the lay-out to another. As many as eight separate points and signal movements may be involved according to the complexity of the junction.

Facilities are provided so that, in an emergency or failure of equipment, separate control can be established for each set of points or signals. This facility is most valuable in locating faults and reduces the system to the standard form as at any non-route controlled cabin.

Installations of this type were expensive owing to the necessity of provision for the duplication of the interlocking between signals and points, effected on the locking frame mechanically and in the remotely controlled circuits electrically on signalling relays.

It was with the idea of developing a cheaper and more simplified form of control that a unique system was developed in which the remote control was applied directly on to the locking-frame levers electro-pneumatically and not into the signalling circuits, thereby retaining the effect of the mechanical lever interlocking and avoiding the necessity of additional relay interlocking.

Two air cylinders controlled by electro-pneumatic valves, coupled to the locking shaft of the lever, move the lever, mechanical interlocking, contact shafts, and electric lock slides exactly as if the lever had been moved by hand.[3]

In consequence of this arrangement the signalling circuits, lever-lock circuits, and mechanical interlocking are all standard as in general use elsewhere, a great advantage from the signal lineman's point of view when tracing a fault. Another advantage is that it is quite safe to employ

telephone-type relays for the control of the electro-pneumatic valves, since no measure of safety is dependent upon them.

A standard relay set is used having six P.O. 3000-type telephone relays with the contacts and coils wired out to four jack strips. The mounting plates, which each carry five such relay sets, are wired according to the circuits required, so that by this method all relay sets are interchangeable and may be replaced within a few seconds for close examination and test.

An abridged relay interlocking is carried out on the remote-control relay sets to maintain order between movements and to prevent unnecessary strain on the mechanical interlocking, but at considerably less expense than if the function was executed directly in the signal circuits.

The air-worked power-frame has separate levers for each signal or set of points and the grouping of levers into routes is achieved on these relay sets.

The resumption of local control at any air-worked power-frame is carried out by the simple process of reversing an air valve adjacent to the frame and thereby disconnecting the air supply to the motors. The signalling circuits do not require to be switched.

The largest installation of this kind was brought into commission in 1948 at Harrow-on-the-Hill, where a mile of complex junctions is controlled by three air-worked power-frames which are remotely controlled from the main signal cabin (*Fig. 24*) mounted above the new station. The relay room is shown in *Fig. 25*.

A power-frame is not an essential feature for the remote-control point and it may be substituted by any form of reliable control instrument, as at Ealing Broadway, where a control desk (shown in *Fig. 26*) is installed on the first floor of a new building to control a 55-lever power-frame on the ground floor, fully equipped for air working, which in turn is arranged to control all signals and points individually.

Transparent control pushes, which affect route control of the signalling, are of a patent type embodying a multicolour visual, red, yellow, or green.

An illuminated diagram suspended at a convenient distance behind the control desk displays the position of any train by the extinguishing of a strip light diagrammatically representing the section of track occupied.

Indications of the colour-light signal aspects are displayed by red or green visuals.

Banner signals which are used for restricted train movements are represented by a white disc having a bar illuminated red when the signal is at danger and green when it is clear.

Telephone and train description controls are mounted on either wing of the desk within easy reach.

When momentarily depressed the internally illuminated individual push-switches, which are provided for every signalled route, cause points and signals to respond for the movement of a train over any desired route.

If for any reason, other than by the normal passage of a train, it is

required to replace a signal to danger, pulling the appropriate control push will effectually cancel the route set-up, and restore the signal lever to normal —so far as the locking circuits permit for the conditions prevailing at the time.

A considerable advantage accrues from this method of control for, whereas it had always been necessary for the signalman to make two movements for each train—(1) that of setting-up the route and clearing the requisite signal before the train proceeds, and (2) the replacing of all point and signal levers to normal again after the passage of the train—it is now only necessary, with this method of push-button control, for the signalman to consider the route over which he intends the train to travel, and to depress the appropriate button. The re-setting is carried out automatically.

An additional feature of the Ealing Broadway control desk is the preselection and storage of routes awaiting the completion of conflicting routes already established ; this aspect is dealt with in the next section.

The Relationship of Signalman and Signal

The steady increase in traffic density has slowly but effectively revolutionized the signalman's relationship with the signal.

With mechanical signalling the signalman had direct and immediate control over the signal aspect displayed, but the increasing frequency of trains rendered this form of control excessive in its physical demands, and power signalling was a necessary relief. Small delays have an accumulative effect, and with still more frequent trains it became essential to introduce some elasticity of working to match the vigilance of the signalman to the early clearing of a signal for the next train.

Whereas previously it had been necessary for the signalman to wait until conditions were safe for a signal to clear before the signal lever was reversed, it now became necessary, in order that no delay might accrue from the signalman's diverted attention, to permit the lever being reversed early and allow the signal to clear as soon as all other conditions were satisfied.

This feature in itself has proved satisfactory and sufficient for the operation of all controlled areas where the signalling is operated from the standard single-stroke frame, with separate levers for signals and points. However, with the introduction of route-signalling capable of handling many more trains per hour, there is an interval of several valuable seconds between the instant of a route lever movement and the ultimate clearing of the signals concerned while the points and crossings are moving in sequence to set up the route. This has been met by a further insertion between the signalman and the signal, for now, as soon as the signal has returned to danger (indicated by the illumination of a red visual behind the lever), he is permitted to replace the lever and make the next required move—even though conflicting with the first. The electrical circuits are

interlocked in such a way that the passage of the first train holds its own route secure and prevents any conflicting movement of signals and points. When safely clear of the junction the re-setting of points takes place and the second route is automatically set up without any further action on the part of the signalman.

In busy traffic and where standard power-frame levers are employed for route working, it is possible to ease the concentration necessary by having two signalmen to operate the frame simultaneously (one dealing with, say, northbound traffic and the other with southbound traffic), but the Ealing Broadway control desk described above is designed for one-man operation and busy traffic conditions are catered for by the provision of pre-selection and storage.

Assuming that no route has yet been set up, the momentary depression of a " push " starts the sequence of movements of points and signals culminating in the clearing of the appropriate signal, always assuming that other conditions are in order for it to clear. The " push " visual simultaneously changes from red, through yellow, to green. If now a second " push " is depressed, corresponding to a conflicting route, this " push " visual changes from red to yellow and no further movement of apparatus will take place until a train has accepted and passed through the first route, or until the first route has been cancelled, after which the equipment will automatically respond to the second route, the visual of which will record the change by displaying green as soon as the second route signals have cleared.

A further step has been taken to ease the peak-hour pressure by the provision of facilities for the automatic working of the Central Line terminus.

Development in Method of Equipment

There have been two major phases of new works in the past 20 years : the Northern and Western Extensions of the Piccadilly Line, 1930–33 ; and the 1935–40 programme for the Central Line, held up during World War II and completed in 1948.

These major works called for considerable recruitment of temporary staff. In the early 1930 programme the labour market for wiremen was reasonably open as a result of the lean years preceding.

In 1935, skilled labour was more fully occupied and recruiting correspondingly more difficult, and at the re-commencement of new works in 1945 skilled staff suitable for the work were unobtainable in the required numbers and it became imperative that unskilled staff should be engaged and trained for the work.

This process was costly owing to the wastage of those who, having benefited by the training and experience, were attracted to more remunerative occupations.

Training met the need up to a point, but a lower standard of skill on the part of the craftsman could not be allowed to affect the high standard of work which is essential for every signalling project if it is to reach the desired degree of reliability.

Care rather than skill is the requisite for the installation of signalling apparatus and this could be met by using unskilled staff under experienced supervision.

In the wiring of equipment, however efficient the supervision, irreparable damage may accrue from bad workmanship which would not be revealed immediately but emerge, with the efflux of time, in failures. It was therefore decided that the wiring process should be mechanized as a safeguard and at the same time as a means of increasing the speed of production.

Mechanization was first applied to the wiring of relay rooms where several thousand ends of wire have to be cut and connected.

Special tools were developed such that the whole process, from the entry of the cable into the relay room to the final connexion on the relay, could be carried out by any wireman without previous experience except the knowledge of the use of each tool, and without danger to the ultimate reliability of the connexion.

The tools and their method of use are described in detail elsewhere.[4]

The insulation stripping tool has presented the greatest difficulty in design because of the rigorous specification necessary to ensure that mishandling cannot damage the wire at the point to which the insulation has to be removed. The stripping tool [4] was of the hot-wire-cutter type, and was certainly safer than stripping by knife, but had the disadvantages of producing obnoxious fumes, and of being cumbersome—slower than the knife in the hands of a skilled craftsman. Heavy copper leads and a transformer were required to supply the $\frac{1}{16}$-inch-diameter Eureka heating element.

A new type of hand tool has been developed to replace the hot-wire stripping tool, and employs cutters shaped to penetrate the insulation without coming into contact with the copper conductor. The accurate location of the wire relative to the cutters is ensured by the close tolerance of the guide through which the wire passes.

In conclusion, the trend in the design, whether of signalling apparatus or method of use, is a continuous process directed and influenced by considerations of safety, reliability, cost, and staff problems, and although spectacular changes are manifested from time to time, it is nevertheless the small day-to-day improvements which constitute the main source of progress in the quality of service offered to the travelling public.

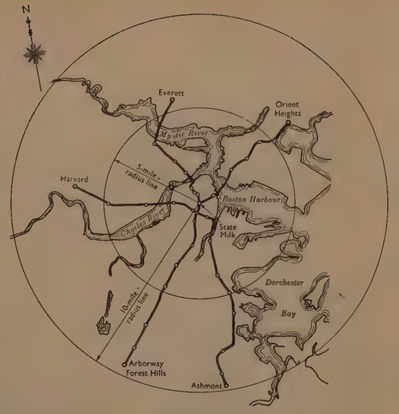
Acknowledgements

The Author wishes to thank Mr P. Croom-Johnson, C.B.E., M.I.C.E., Chief Engineer, London Transport, for his permission to present the

FIGS 1

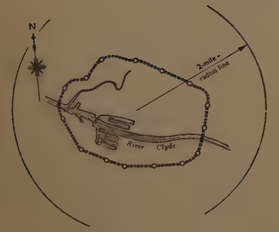
LONDON

PARIS

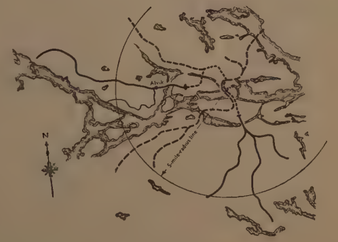


BOSTON

NEW YORK

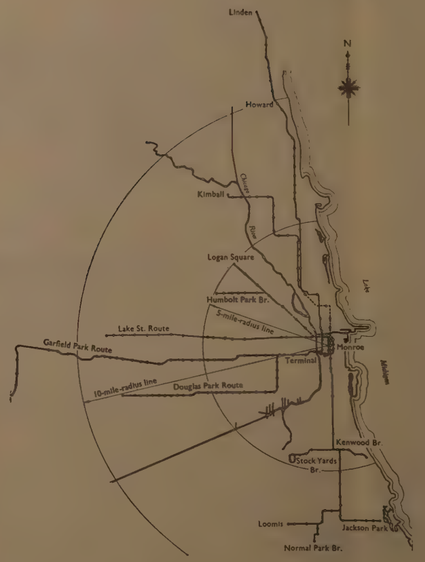


GLASGOW



STOCKHOLM

ROME

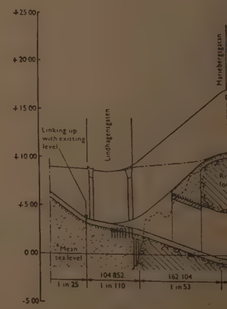


CHICAGO

SAN FRANCISCO

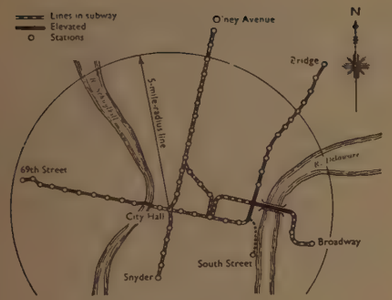
Figs 1

Figs 1 Fig.3

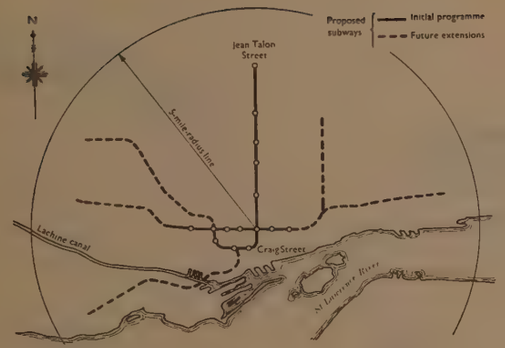


WILLIAM CLOWES & SONS, LIMITED: LONDON

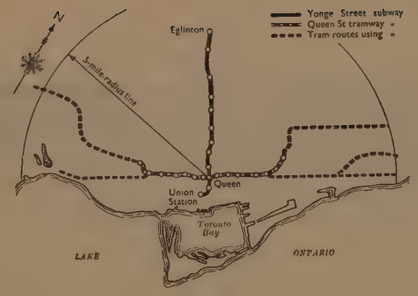
PLATE I
UNDERGROUND RAILWAY DEVELOPMENTS



PHILADELPHIA

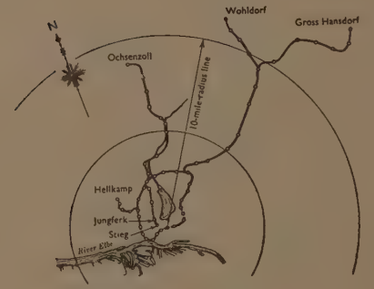


MONTREAL



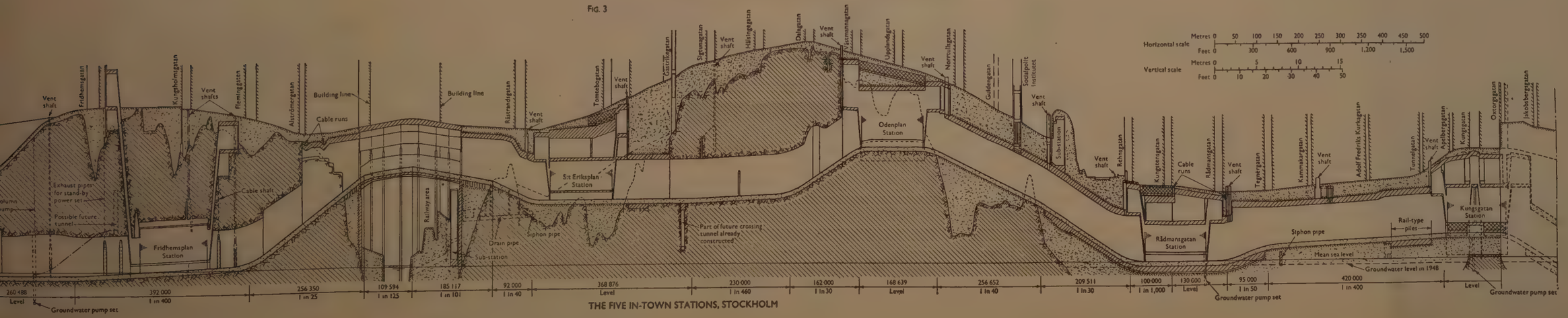
TORONTO

BERLIN



HAMBURG

Fig. 3



THE FIVE IN-TOWN STATIONS, STOCKHOLM

D. H. COOMBS and G. J. WILLSON

information contained in Part 2 of the Paper, and Mr R. Dell, M.I.Mech.E, M.I.E.E., Signal Engineer, for his helpful criticism and guidance in the course of its preparation.

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6. T. S. Pick and R. Dell, "Review of British Underground Railway Practice." Proc. Instn Elec. Engrs, vol. 97 (1950), Pt Ia, p. 27.

The Paper is accompanied by sixteen photographs and twenty sheets of drawings, from which the half-tone page plates, folding Plates 1 and 2, and the Figures in the text have been prepared.

Discussion

The Chairman, in moving a vote of thanks to the Authors, said that he had always had a great admiration for what London Transport did, knowing their difficulties and not understanding very much about the inside working. He had been a little disappointed to learn that other cities had evolved something bigger than London Transport, because he had always fancied that the London system was the largest in the world. However, he had been pleased to have his attention drawn to some respects in which London Transport was supreme, for example, that the number of trains per hour worked through was greater in London ; he noted that even Glasgow had a steeper gradient than any other underground railway in the world—1 in 16. Part 1 of the Paper was a very interesting record, and the Author must have gone to immense trouble to obtain information from the United States and Europe. He would regard the Paper as something to which he could refer and without which he might have made some idle and incorrect comparisons with an American about Chicago, New York, or even San Francisco.

Part 2 of the Paper was invaluable in that it showed the progress

that had been made by London Transport with their very intensive working; the keynote was reliability. The Author had quoted figures of the improvement in reliability, and when one took account of the multiplicity and complication of the apparatus concerned, together with the short time available for attending to it, the results were wonderful.

A feature of the Paper which seemed outstanding was the preference, after long experience, which London Transport had for electro-pneumatic rather than electrical forms of power signalling. He was thinking also in that connexion of the trainstop, which was an extraordinarily neat job.

Knowing more about the main-line railways, although not a signal engineer, he said that the difference between main-line railways and London Transport was such that he would also value Mr Willson's part of the Paper considerably, for reference purposes. He suggested that London Transport was to be admired with regard to both operation and signalling.

Mr W. P. S. Cockle said that the planning, design, and equipment of an underground railway exhibited so many facets of an integrated whole that one frequently came across a Paper on the subject of some particular work, entailing a high degree of careful study by the Author which caused one to appreciate the extent to which he personally had been involved in the success of the project.

The present Papers lifted a veil from the activities of many departments and individuals, and would make all concerned appreciate more fully the contributions of others.

Table 2 showed that New York and London were both signalled for 40 trains per hour, but that New York actually ran only 32 ten-car trains against London's 38 eight-car trains. He believed it had been found that trains of more than eight cars in length required extra staff for efficient handling on an intensive service in a busy station—perhaps the proposal to place the guard in the middle of the train might improve that position. Could Mr Coombs say whether that accounted for the fact that New York had fewer trains per hour?

He commended to Mr Willson's notice that Oslo ran 42 trains per hour with no signals.

On the planning of railways generally, he observed that the statistician had to contend with the same difficulty as the accountant—arithmetic was only one-half of the matter. The provision of a new traffic route could so modify the statistics that brought it into being that they became unrecognizable within a few years.

For instance, when the Piccadilly Line had been extended to South Harrow and Uxbridge, and to Hounslow, the proportion of trains on the two branches had been 1 to 1. That proportion was now 2 to 1.

When satellite towns had been mooted, it had been intended that their residents should mainly be employed in local industries, but since the building of dwelling houses had outstripped that of factories, there was a

tendency for them to become mere dormitories and to throw unforeseen burdens on the transport to the nearest large town.

He was aware of an area near a certain metropolis where it was not considered that the demand would justify expenditure on improved travelling facilities. Why? Because among the residents was a high proportion of retired people. And why that high proportion? Because the travelling facilities were poor!

On the spacing of stations, it was true that it was possible to fix the optimum spacing having regard to the train speeds and the means of bringing the passengers to the stations; but in any large town such as London the positions of the stations nowadays was usually determined by the focal points of traffic and the interchange facilities required with other lines. In a recent study of a route for a new tube, it had been found that out of seventeen stations all had been fixed by those latter considerations—actually, fifteen railway connexions and two as focal points of road traffic.

A trend in underground-station design not mentioned in the Paper was to provide completely different routes for incoming and outgoing passengers, especially at busy interchange stations.

On the possible steepening of grades to allow shallow-depth stations, one was reminded that the electrified metre-gauge railway from St Gervais les Bains le Fayet to Vallorcines had gradients of 1 in 11, although entirely dependent on adhesion. He was all in favour, however, of the highest standards of gradients and curvature to allow for progress in speed. Many sharp curves were a legacy from the days when the standard had been set by much lower speeds than those that could be achieved today.

Mr Coombs's self-propelling soil-compressing earth mole, of course, had been used in silt under river beds. It simply pushed the spoil upwards. Mr Cockle did not think that it could be taken too seriously in any subsoil firm enough to build on. There was the point, too, that there was only the skin of the lining to take the reaction from the thrust of the shield jacks.

The use of reinforced concrete for tunnel or cut-and-cover construction in water-bearing ground was so much related to the question of whether site conditions rendered it reasonably practicable in each case, that he could not dilate upon it, but he was glad to learn that when Mr Coombs had spoken of preserving the integrity of the waterproofing he had meant asphalt, and not that he was relying on the watertightness of the concrete. It could not be repeated too often that in subterranean jobs necessitating the changing of timber and the forming of construction joints, a concrete structure was no more waterproof than the first crack that developed.

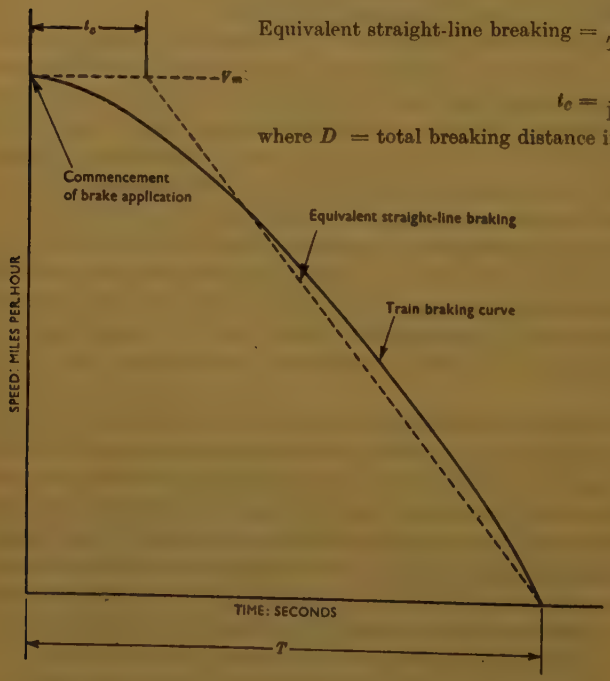
Mr Willson's reference to the elimination of reinforced-concrete troughing because of the introduction of ten-core cables was welcomed by all who had to provide an obstacle-free path for staff to reach stabling sidings and the like.

Mr Cockle showed two lantern slides illustrating the lay-out of cable-runs which could, with advantage, be re-laid with the new cables.

Mr H. R. Broadbent showed a slide, reproduced in *Fig. 27*, to amplify a point made by Mr Coombs in connexion with equivalent straight-line breaking.

In that Figure, speed was plotted against time of a train coming to rest after the application of a brake from a speed V_m. The coefficient of friction of a brake-block was not constant, and as the train slowed up, so the coefficient changed and the rate of braking altered. In the consideration of train movement it was not possible to work out a separate curve each time a problem was studied, and the curved line was therefore replaced in the consideration by two straight lines, an equivalent straight-line braking line and an equivalent coasting period t_c. The area enclosed by the two dotted straight lines was equal to the area enclosed by the full line, and therefore the two distances were equal. The total time was also the same as that of the train coming to rest.

Fig. 27



The method also provided a useful tool for an examination of the actual braking of a train. It was unnecessary, of course, that the shape of the curve should be known. As could be seen, the formulae included

distance, time, and speed. The figure of 2·6 miles per hour per second mentioned in the Paper for London Transport as the full service rate of braking was an equivalent straight line with a t_c of approximately 2 seconds. Referring to ordinary service braking, a figure of 2·25 miles per hour per second was used.

With reference to the hump system on the Central Line, where a certain claim was made for a saving in energy consumption, it might be advisable that the proposed system should be re-examined in the light of greater knowledge of train movement. The idea was put aside, he thought, because, with the improved braking, drivers could commence to brake almost at the end of the platform, and the approach gradient was therefore no advantage; and further that it was a positive disadvantage where any checking back took place, and trains were held at a home signal on the steep approach gradient. Trains so held would be slow in clearing the train in the rear.

A preliminary examination had been made of what would happen if the system in use on the Central Line of 1 in 30 down out of a station, followed by some level running, and subsequently 1 in 60 up into the next station, were to be replaced by what might be called a saw-tooth system in which the train left the station on a steep down gradient and immediately started to climb back.

The earlier energy was imparted to a train in a run, the more effective it became, because it was available for a greater proportion of the run; the energy put in towards the end of the run was very inefficient, and the nearer the end of the run the less efficient it became. The 1-in-30 gradient which was used on the Central Line produced a much higher rate of acceleration, and the train attained speed more rapidly with consequent more economic use of the energy supplied.

If one were to devise a system on the saw-tooth principle—going out of the station on a 1-in-20 gradient with a 20-chain vertical curve as on the Central Line—then there would be a very distinct advantage in reduction in run-time; and if one worked on the principle of running up on a 1-in-200 gradient, with a vertical curve of 40 chains, there was an immediate reduction in energy consumption which, with the minimum allowances for make-up time, was, for ½-mile runs, of the order of 12 per cent.

It therefore looked as if the matter might be re-examined, and Mr Coombs had performed a very useful service in drawing attention to the point. There was the objection, which Mr Broadbent had already mentioned, that if the driver were held at the outer home he was on a gradient; but the maximum speed at the signal was reduced (curiously enough, running down and up reduced the maximum speed and did not increase it) and therefore the overlap was shorter; and, in addition, since the train was on a gradient benefit was derived and a further reduction in a shorter overlap resulted. The combination of the two meant that, although the train must accelerate from standstill on an up

gradient, it did in fact take less time from the moment it moved from the signal to the moment it came to rest at the station. In the particular case of a ½-mile run, a saving of run-time of no-coasting of 1½ second had been calculated, compared with the run-time on a level track, combined with a possible saving for equal run-time, already mentioned, of 12 per cent.

Mr John Ratter, referring to Mr Coombs's remarks regarding "non-philanthropic welfare economics," which he gathered meant "subsidies," supposed that, more than anything else, economics affected the design of any engineering project in present days, and particularly did it affect transport in London. There had been tremendous public resistance to paying additional fares in recent years, and at the same time that resistance had coincided with an increasing need for the public to pay them. He thought that the attitude of the public towards transport was to assume a right to very cheap and even uneconomic fares, and he felt that that would be reflected in what happened in the future, whatever political party might be in power.

The combined growth of London caused the demand for new tubes, increased travel facilities, and faster travel to become increasingly urgent with every year that passed, and at the same time the cost of providing those facilities could not be carried economically without a subsidy or a substantial rise in fares. The problem was therefore an extremely difficult one, and it stressed more than anything else the need for the maximum economy consistent with safety and efficiency that engineers could achieve.

He had been very interested in the mention of the mole, but rather disappointed to hear from Mr Cockle that apparently it worked only in mud and not in clay. It seemed probable that since the last tubes had been constructed there had been a great deal of study of tunnelling methods in clay, and he would be pleased to hear if Mr Coombs knew of anything new which might be expected in any new tube construction.

It seemed to him that the spaciousness of stations and the standards to which they had been accustomed in London Transport in the past could not be expected to go on in the future.

On first joining London Transport, he had been a little surprised to find that the tracks in the tunnels, apart from their being set in concrete, were the traditional railway track-rails carried on chairs on wooden sleepers. Since there were only 3 hours at night and a little more time at the weekend for track maintenance, instead of all day as on the main-line railways, one might expect a different type of track. Perhaps the main difference between London Transport and the main-line railways was the use of long welded rails, with the excellent results that one could experience by travelling at any time from Liverpool Street to Stratford, giving the sensation of gliding on ice.

He felt that in new construction, with new tunnels being developed as was bound to happen in the course of the next 10 or 15 years, there was a

very big field for considering whether a totally new kind of track construction in the tunnels was a possibility, for example, the use of flat-bottom rail and the discarding of some of the less stable things in the present track design which gave trouble. It seemed that in that direction would lie one of the biggest improvements that might be possible in new tube construction, because in that way it might be possible to alter the method of maintenance and save on the cost of maintaining the track in the tubes.

Mr R. C. Hider said that operating men had a special interest in learning what engineers were doing and, perhaps more important, what they were thinking of doing.

He noted that the Paper mentioned deep-level tubes, and Mr Coombs had given very good reasons why some underground railways must be deep, although they were not very attractive to passengers and, speaking as an operating man, he could say that they were not always very attractive to operating men. He was a little disappointed that engineers did not seem to be giving the attention one might expect to the vertical transport between the street and the platform, which was a very difficult matter.

Escalators had been mentioned, and perhaps some people were inclined to think that escalators were so very much better than lifts; but he knew a number of operating men who, like himself, had felt that there were occasions when lifts were to be preferred to escalators. An escalator went on until one stopped it, and even when it was stopped that did not necessarily stop the people coming. With a lift it was possible to stop a movement one way or the other.

There was another point on escalators, and he did not know what was the answer of the railway engineer. It might be because of weight of the traffic, but an escalator was usually in a very long inclined shaft; whereas one could go to a large department store, for example, and find there a series of short flights, which seemed to him to offer a number of advantages from the point of view of construction and of traffic movement and traffic control. There was, moreover, the advantage that if one of those shorter escalators had to be taken out of service, the distance which people had to walk down a stationary escalator was less.

Arising from the problem of vertical transport was the problem of storage space in the ticket hall and somewhere between the ticket hall and the platforms. Whether Mr Coombs intended the mezzanine floor to be of the Moscow or, as one preferred to call it, the Gants Hill type of construction, he was not sure; but operating men would welcome that type of platform concourse at all busy central-area stations.

Finally, because of the depth, there was the problem of ventilation. Mr Coombs had referred to it solely as ventilation; but the engineer on the site was concerned, not only with cooling, but also with getting rid of some of the rather excessive air pressure that persisted in some parts

either of the tubes themselves or of the tube platforms. Mr Coombs had explained what was done, and (so far as he could gather) the escalator shaft was used either to drag some air in or to push some out. It seemed that Mr Coombs felt that the sort of velocity involved was quite reasonable, but many of the operating men and many of the passengers considered that very nearly gale force was reached !

Mr J. K. Anderson said that it had been his privilege to see a little of the tunnelling work in Toronto, 2 years previously, in connexion with the subway that was being built there, and it might be of interest to say a few words on the methods and the cost.

The construction had been of the cut-and-cover type, and the special feature had been the very large amount of temporary work. In one instance at least 200 yards of street had been completely timbered ; the tramway tracks had been taken up, excavations down to about 8 or 10 feet had been done, the tramway tracks and the street had been put back, and then the tunnelling underneath had been done. The construction thereafter had been concrete in a fairly conventional style.

The length of the route had been only 4½ miles, and in that length there were twelve stations, so that the stations were exceedingly close. The plan had been to connect up the new railway with the tramway system, and envisaged the running of single-decker trams in the subway itself, if need be, at a future date. Special care had been taken to have a good connexion between the stations and the surface traffic. He was glad that that point was mentioned in the Paper, because it was a matter that needed a good deal of attention. In a great many places today the stations and bus stops were a very long way apart.

It was estimated that the cost of the subway would be 48 million dollars, if the cost of the rolling stock and equipment were included, or roughly 33 million dollars for the civil engineering works. The total cost worked out at about 10 million dollars a mile, and taking into consideration the value of the pound, etc., that figure was very closely related to the figures for cost given in the Paper.

He was pleased to hear Mr Coombs mention that experiments in connexion with tunnel work, were in hand. The experiments were going ahead slowly, and were concerned with precast concrete segments. They had been used as mentioned in the Paper, and some of the other ideas that were being looked into included caulking of the segments to see whether they could be made as waterproof as cast iron. Another experiment related to the elimination of bolts and to designing the tunnel and the lining in such a way as to eliminate grouting. By those means, and with vibrated concrete, he thought there was every hope that costs of tube tunnelling would be considerably reduced.

He would like to know more about mole tunnelling, which seemed a possibility ; but if the ground was sufficiently soft and was water-bearing, there was the question of compressed air to be taken into account, and

in that case the cost would go up by at least one-and-a-half and possibly two times.

Mr A. H. Toms, referring to the question of mole tunnelling, said that stiff London clay contained about 30 per cent moisture, and very little in the way of air voids. It was therefore virtually incompressible except under prolonged application of load. In consequence, it seemed to him that there would be upheaval of the surface anywhere that mole tunnelling was carried out, unless at very slow rates. Moreover, if the pressure was sustained long enough to allow the consolidation to take place without disturbance of the surface, there would be an ingress of water into the tunnel as driving progressed, and it would be necessary to get rid of a very high percentage of the volume of the tunnel as water. Consequently, it appeared to him that, theoretically, at least, in London clay there would be great difficulties in applying that tunnel-driving technique.

Mr A. R. Telford asked the Authors why separate platforms for passengers entering and leaving the train had not been provided in busy underground stations, as at certain surface stations, notably Golders Green. At Leicester Square and Tottenham Court Road, for example, it was very difficult during the rush hours to get out of the train because of the people crowding round the doors. Mr Coombs had stated that the latest Paris articulated stock was designed to provide door space of 36 per cent of the total area of the side, but when people filled up that area it became 10 per cent! Was it purely economics that stopped two platforms being constructed per track at underground stations?

Mr J. C. Hill observed that in Mr Willson's part of the Paper it was stated that single-core 0·064-inch-diameter cables were used. In the house-building industry there was a preference for three-strand 0·029-inch-diameter cables. He would be interested to know whether there had been any trouble with the single-strand cable.

*** **Professor Herbert Addison** considered that the Paper offered an opportunity for travellers in London to say how highly they valued the services that the underground-railway system provided. Having made his first journey on the system on the first day of the twentieth century, he was in a position to assess the uninterrupted progress that had been recorded, and his questions were therefore those of a deeply interested and appreciative observer.

Could any further information be given about the relative performance of "tube" trains and surface (District or Metropolitan Lines) trains? Selecting two representative busy stations, say Piccadilly on the Piccadilly Line, and Charing Cross on the District Line, what was their normal rush-hour capacity per platform? How many passengers per hour were moved westward at the busiest time?

*** This contribution was submitted in writing upon the closure of the oral discussion.—Sec. I.C.E.

Were comparative running costs per passenger mile available, say, for stretches of line where both tracks ran on the surface, for example, the Piccadilly Line from Hammersmith to Uxbridge, and the District Line to Upminster ? Did the lighter weight and smaller size of the " tube " cars contribute to more economical working ?

Still another type of comparison concerned the eastward extension of the Central Line to Epping, where electric traction had superseded steam traction. Was it too soon to say what effect the change was likely to have upon cost per passenger mile ?

The important question of noise in tube trains was mentioned briefly in the Paper, chiefly in connexion with the Paris Metro pneumatic-tired train. But had not the London tube railways made experiments in that direction some years ago ? Had not special linings been applied to an experimental length of tunnel north of Baker Street ? Would the Authors say whether any further efforts to reduce noise were contemplated ?

Since the scope of the Paper clearly did not exclude discussion of future extension in (or under) London, it was interesting to speculate where such extensions might most usefully be made. Perhaps it would be asking too much to suggest a tube station that would make the Institution building more accessible from the north ; but the possibility of a link between Paddington, Marble Arch, Hyde Park Corner, and Victoria did seem worthy of study. It would usefully fill in the gap between the north-south Bakerloo Line beneath Regent Street, and the western part of the Inner Circle on the District Line at Notting Hill Gate.

As compared with underground-railway systems in other cities throughout the world, the London Transport railways had one unique advantage : they incorporated one of the greatest pioneering engineering enterprises of the past. That was the Thames Tunnel, the first tunnel ever to be driven beneath a river, and even now the farthest downstream of any of the tunnels beneath the River Thames used by London Transport trains. Completed by Marc Isambard Brunel in 1843, it was never used for vehicular road traffic, but was eventually adapted for the steam trains of the East London Railway. At present the Metropolitan Line service from Whitechapel to New Cross traversed the twin tunnels ; passengers who alighted at Wapping Station could see the north portals of the tunnels substantially as Brunel left them. The surface buildings at that station had been destroyed during the war, and Professor Addison had suggested to the Institution some years ago that when they were reconstructed, a space might be found for some kind of memorial tablet commemorating Brunel's work. Perhaps the Authors could say whether it had been found possible to carry out that proposal ?

Mr D. H. Coombs, in reply, said that he was not in a position to give any factual answer to Mr Cockle's query as to whether the greater number of trains per hour run in London, as compared with New York, was a consequence of the length of the trains ; he could only conjecture

that the overall operating conditions in New York made the operation of more than thirty-two trains per hour impracticable, in the same way that in London it was possible, in certain conditions, to operate forty trains per hour and, in other conditions, not more than thirty-two trains per hour. There were a variety of reasons why that might be so. He would not attach great importance to the length of the train up to ten cars and the ability of the guard to exercise effective and quick control of the train—but on that matter he was speaking without any authority; it was simply a guess on his part.

With regard to insulation, what he had had in mind was not strictly asphalt, but asphalt or bitumen multi-ply felting.

Mr Cockle had shown a picture in which the concrete manhole covers were standing proud of the cesses in which they were placed. London Transport, at least in the section with which Mr Coombs was familiar, had eliminated that construction some time ago, before changing to the fabricated steel-slat cover. They were now putting manhole covers flush with the frame in which they were placed, and the frame was flush with the surrounding ground.

Mr Broadbent had made a plea for a steeper gradient out of the station. Mr Coombs thought that the main point about applying a steeper gradient out of the station was that it involved one of two things—either reducing the minimum vertical radius from the station ground on to the run-out gradient, or shifting the curve longitudinally out of the station. The difference between the length of the vertical transition curve between 1 in 20 and 1 in 30 grade would be of the order of 90 feet for a 1-mile vertical radius—a considerable distance—which would mean that unless the vertical curvature of the transition were reduced, the down gradient would have to be farther out of the station, which would detract from its effectiveness.

Another point was that if the transition between a gradient of 1 in 20 and the flat was likely to be of the order of 200 feet, he thought it was clear that by the time one had put in a transition at the top, bottom, and farther side of the saw-tooth one would nearly have got from one station to another, particularly if it were intended to allow a level run-in clear of any brake application. Of course, it might be possible to reduce the vertical transition curves; they were based on sensations of sinking or sensations of getting an upward shock, and those things were by nature arbitrary limits. But the standard vertical radius employed on London Transport, which was 1 mile, was only about one-half of what had been adopted when laying out the new Stockholm Railway. The minimum vertical curve on the Stockholm system was 3,000 metres, which was nearly 2 miles. Thus they were not unduly conservative on London Transport in their requirements for a minimum vertical curve.

Caution was needed in reducing vertical curves, because once constructed in a tunnel subsequent alteration to them would be prohibitively costly; and it was sometimes necessary to institute non-stopping at particular

stations. The maximum falling grade permissible raised questions of operating expediency.

Mr Ratter had observed that he had read " welfare economics " to mean a subsidy. Personally, Mr Coombs had not felt that. " Subsidy " was a word that neither he nor most people liked ; but he thought that in considering the costs of tube railway construction it was a good thing to recognize that tubes, like roadways, could put up rateable values in outer urban areas and might very well prevent rateable values from coming down in inner urban areas. Colonel Bingham, in his report on the San Francisco projected railway system, had said that, in his view, the civic authorities of San Francisco should endeavour to apply the formula of charging commercial residents and property owners in the central area some portion of the cost of constructing an underground railway, because if no underground railway was built deflation of property values in the commercial centre of the town would be inevitable. Colonel Bingham had therefore said that it was right and proper that the community ought to shift some of the burden of tube construction costs from the citizens at large to the property owners in the centre of the city.

Another point to be borne in mind was that the cost of running a bus through a city was dependent upon the number of buses and other vehicles run. There came a point at which road traffic strangled itself, that was to say, the marginal cost of transporting people by road through a city was, in the nature of things, a rising one, and it was kept down by the presence, in large cities, of underground railways. In other words, in the absence of underground railways, the marginal costs of road transport in the large community could become prohibitive. The building of a tube could reduce marginal and average costs of urban road transport, both public and private.

Those considerations—the effect on rateable values, the effect upon costs of alternative forms of transport, and the cost of the alternative of road widening—were, Mr Coombs thought, quite properly part of what he had called welfare economics and should reasonably be reduced to some sort of money measurement in examining a case from a community's point of view for or against the building of a tube railway.

Mr Hider had made a number of comments about escalators, but Mr Coombs did not feel qualified to deal with them. As to the mezzanine floor, which was not a platform-level concourse, the arrangement at Gants Hill was a technical innovation. He recognized that the criticism had been made that it might, with greater usefulness, have been placed nearer the centre of affairs ; but technical innovations, when they came along, had to be placed wherever it was possible. If at the time of the conception of the idea one was building a line remote from the centre, he thought it wise to carry out the technical innovation there, and to examine the experience gained before putting it in at the centre. One either put the innovation in where opportunity offered, or kept it for a long time in cold storage until

the opportunity arose of putting it at an important central station—which might not come for a generation. Technical progressiveness urged that new things should be tried as and when they could, subject to economic realism.

The arrangement at Gants Hill was different only in scale from what had existed for many years now at such places as Hyde Park. There was a loftier ceiling, but the general lay-out was not substantially different from what had long been recognized as desirable for decanting passengers on to the platform and at the same time taking them off, without too much conflict at any points of intermingling.

Ventilation, about which Mr Hider felt strongly, was a problem mainly of heat extraction from the tube tunnels. It was not a problem of equalizing pressures or of dissipating the draughts caused by train movements. Most draughts were caused by the necessity for extracting large quantities of heat from the tunnels by the movement of large quantities of air. If that had to be done, there would be draught problems, and all that could be done was to keep them at the minimum level where economy was balanced with a reasonable sense of public amenity.

Mr Anderson had asked for information on mole tunnelling, and other speakers had expressed an interest in it. He was not able to give more information than that contained in the following translated extract from *Der Aufbau* for October 1952 :—

> " This principle of under-earth digging has now been applied by Russian engineers to a newly designed subsoil vehicle. The " under-earth boat " is a cigar-shaped machine fitted in front with a powerful drill and in the rear with finlike projections which correspond to the rowing feet of the mole ; in addition, there is an endless worm-gear surrounding the body of the boat which has the same purpose as the neck movement of the mole, namely, to press the excavated soil against the walls. Thorough research showed very soon that the power input becomes smaller if the earth is cut at a higher speed. The worm-gear is therefore designed for a high rotating speed, the speed being naturally dependent on the type of soil encountered.
>
> " It is reported that Moscow already has a third machine of this kind under construction. Its purpose is to aid in the laying of gas mains, district heating mains, and sewers. These works can now be carried out exclusively underground so that it is no longer necessary to break up the road, as has always been the case hitherto."

Mr Telford had asked whether it was entirely a matter of economics that prevented two platforms being constructed, one for people getting on and another for people getting off. One might think of quite a number of reasons why it would be desirable and why it would be undesirable, but naturally economics governed every activity of an engineer, or of anybody else who was controlled by some person who had to supply money or to

justify the supply of money. He thought it could be said that there were wider platforms, more ample platforms, and sometimes more platforms for stations in the open than for stations in the tubes because of the enormous cost of providing space in the tubes. It was necessary to temper the desire for technical perfection with responsibility in the spending of money which ultimately the public would have to provide in fares.

Professor Addison's several questions were not easy to answer fully. The rush-hour capacity of a station was largely dependent on the rush-hour capacity of the line and that contained many variables, some of which were very short-term in effect. Similar considerations applied to comparing tube and surface train performances. On tracks of similar alignment and contour it was unlikely that there would be much difference in the unloaded ton-mile energy requirements outside of increased tractive resistance owing to the air-pumping action of tube trains. But the loaded-car-mile figures would of course be dependent upon the loads carried, and those would be dependent upon the load factor on the line both as a whole and with respect to the various sections.

Substitution of electric traction for steam traction had almost always been followed by an increase of traffic. Cost per passenger-mile was only a partial index of the change, for electrification had in fact always been accompanied by an improved service, and it was that increment in public amenity which was perhaps the most significant economic aspect of urban passenger-service electrification.

It was the present standard for all new tube construction to fit sound-deadening slabs to the tunnels and also to fit long welded rails.

Professor Addison's suggestion of a commemorative tablet in connexion with the work of Marc Isambard Brunel had been noted.

Mr G. J. Willson, in reply to Mr Broadbent's remarks on the hump system, stated that he heartily supported the idea of having humps in tube construction because, apart from energy saving, there were advantages from the signalling point of view if the rising gradient extended, say, 1,000 feet from the rear of the station. In that area, with close headway working, there existed the maximum concentration of signals, each of which could be placed nearer to the station, thereby reducing the minimum interval between trains to less than would be obtained with level tracks.

With regard to Mr Hill's point about the use of single- and multi-stranded cables, the use of the single-stranded copper cable was standardized for signalling circuits at the time of the original installations of electrical signalling.

The use of 3-strand 0·029-inch cable was considered unsuitable for producing a consistently reliable connexion on apparatus where the wires were terminated in the form of a loop secured between washers by 1 B.A. nuts. With that method of termination, the multi-stranded cable had a tendency to spread and work loose, but it had one advantage that if a strand was slightly damaged while the insulation was being removed, any

complete fracture of the strand would not necessarily break the circuit; whereas with a single strand, careless stripping and marking of the copper might lead to a complete fracture later. For that reason every care had been taken in stripping the insulation from the wire and in making the loop, even to the use of the special tool described in the Paper, and it was extremely rare for a failure to occur which was attributable to that cause.

The closing date for Correspondence on this Paper has now passed without the receipt of any communication.—Sec. I.C.E.

ROAD ENGINEERING DIVISION MEETING

31 March, 1953

Brigadier A. C. Hughes, Member, Chairman of Division, in the Chair.

The following Paper was presented for discussion and, on the motion of the Chairman, the thanks of the Division were accorded to the Author.

Road Paper 41

"Factors Affecting the Riding Quality of Machine-Laid Concrete Roads" *

by

Reginald Herbert Honley Kirkham, B.Sc., Ph.D., A.M.I.C.E.

SYNOPSIS

Measurements of the surface profiles of machine-laid concrete roads have suggested that the riding quality might be improved by closer control of the methods of construction. To study this matter tests were made during the construction of two roads on which two different spreading and two different finishing machines were employed.

The performance of the machines was investigated with a profilometer specially designed to record the irregularity of the concrete surface after each pass of the finishing machine. Using this instrument it was found that the evenness of the finished surface, the uniformity of the compacted concrete, and the number of finishing passes required depended primarily upon the evenness of spreading. With either spreading machine it was possible to produce a fairly uniform density in the spread concrete and hence a road with good riding quality, but the technique required was elaborate and inconvenient. The effectiveness of the finishing machines for removing irregularities left by the spreading depended upon the weight, shape, and method of mounting of the oscillating screed.

The opportunity was taken during the tests to measure the accuracy of setting of the formwork and the deflexion of it under the machines, and to examine the irregularity caused by the joints. Uneven setting and settlement of the formwork were responsible for about one-quarter of the total irregularity in the best surfaces, and the use of a stretched line was considered for setting the rails on which the machines were actually run. The amount of irregularity at joints was found to depend upon the type of joint, dummy joints giving rise to the smallest bumps.

Introduction

Measurements made by the Road Research Laboratory during the last few years have shown that the riding quality of machine-laid concrete roads is generally not as good as that of the best hand-finished work.[1] Although there was this general difference it was observed that substantial lengths of the work finished by several types of machine were of good surface quality,

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[1] The references are given on p. 686.

and that none of the machines tested was inherently incapable of producing a good finish. This suggested that a better overall result might be expected from closer control of the various constructional operations.

To study this matter, tests and observations were made with the co-operation of the Ministry of Transport and the County Surveyors concerned, during the construction of a new diversion on B.4265 at St Athan, Glamorganshire (Site 1), and during the reconstruction of A.46 at Six Hills, Leicestershire (Site 2). The factors examined were :—

(1) The type and method of operating the spreading machine.
(2) The type and method of operating the finishing machine.
(3) The accuracy of setting of the formwork.
(4) The type of joint.

Details of the Construction and the Tests

Construction

For both roads the carriageway was 22 feet wide, and was constructed in two lanes each 11 feet wide. The crossfall was generally of the order of 1 in 40 but over one length at Site 1, where there was a sharp curve, it was increased to about 1 in 20.

Site 1.—The concrete slabs were 60 feet long between expansion joints with no dummy joints, and were 8 inches thick with a single layer of reinforcement 2 inches from the top. The subgrade was a fissured limestone which was brought up to its final level with similar material and covered with 2 inches of rolled ashes.

The aggregates used for the concrete consisted of two sizes of crushed limestone of 1½ inch and ½ inch maximum nominal size respectively, a coarse sand known locally as " channel gravel," and a fine sand to correct for the coarse grading of the channel gravel. The mix proportions were 1 : 7·5 by weight, with 37 per cent sand and a water/cement ratio of 0·49, which gave a compacting factor of about 0·79 and an average strength, measured on 6-inch cubes, of 7,250 lb. per square inch at 28 days. The control of the quality of the concrete was undertaken by the Road Research Laboratory; it resulted in a standard deviation of 870 lb. per square inch. This represents a degree of control which, although normal in this class of work, can only be considered to be fair.

The concrete was mixed in two 14-NT mixers and transported to the site in end-tipping lorries, each lorry being generally loaded with four batches. The method of constructing the slabs was to spread concrete to a depth of about 6½ inches, lay the reinforcement, and spread further concrete to give a surcharge of about 1½ inch. The forms were laid on a thin bed of a sand-cement mix and were generally secured in position a few days ahead of concreting. The machines were not run on the forms but were carried on 25-lb.-per-yard rails supported on, and keyed to, the stiffeners in the forms. The rails were either 18 feet or 24 feet in length, so that it was not

always possible to locate the rail joints over stiffeners ; the rail joints were therefore made with two fishplates held by two bolts in each rail.

The expansion joints were constructed by means of special equipment [2] designed by the County Surveyor of Glamorgan, and the stop-ends were made by the same method. With this equipment the top of the filling material was held during construction by an H-bar which was supported from the side forms, and strips of concrete about 2 feet wide were manually tamped to a level about 2 inches below the forms on each side of the joint before the main concrete was spread. This hand-tamped concrete was intended to prevent movement of the dowel bars and of the bottom of the filling material during the compaction of the slab.

Site 2.—The slabs were laid on a bituminous carpet on an old concrete road and were 6 inches thick with a single layer of reinforcement 2 inches from the top. At the beginning they were made 150 feet long with dummy joints at 25-foot intervals but after about two-thirds of the first lane had been constructed the dummy joints were omitted and the slab length was reduced to 100 feet.

The aggregates consisted of two sizes of irregular gravel of $\frac{3}{4}$ inch and $\frac{3}{8}$ inch maximum nominal size respectively and a $\frac{3}{16}$ inch down natural sand. The mix proportions were 1 : 6·5 with 40 per cent sand, and a water/cement ratio of 0·55 by weight. With this mix the compacting factor was 0·80 and the average strength of the concrete measured on 6-inch cubes was 6,150 lb. per square inch at 28 days. The standard deviation was 680 lb. per square inch so that the standard of control was better than that at Site 1.

The aggregates and cement were batched by weight about 8 miles from the site and transported in tipping lorries subdivided to take 3 or 4 batches to a 1-cubic-yard Paver mixer at the site. To construct the slabs the concrete was spread to a depth of 5 inches, the reinforcement placed and further concrete spread for the top course. Since the method of spreading used at this site gave less precompaction to the concrete than that at Site 1, a surcharge of about $1\frac{1}{2}$ inch was again found to be necessary, although the thickness of the slab was 2 inches less. The forms were of the same type as those used at Site 1 and were laid about 2 days before concreting on a thin bed of sand-cement mix, so that small depressions caused by the settlement of the old slabs could be eliminated. Holes for the stakes to hold the new formwork had to be drilled in the old concrete since the original carriageway was 23 feet wide, and to reduce the amount of work the forms were staked at the ends only.

The expansion joints were made by the same method as at Site 1, but there was insufficient labour available for it to be possible to do any hand tamping and so the 2-foot-wide strips were omitted. At the end of each day's work the stop-ends were not made in this way, but the filling material for the expansion joint was placed against battens. These battens were difficult to hold in place during the finishing process and there was often

some movement of the joint. When dummy joints were used they were formed with precast concrete units to support about 1½ inch of filling material at the bottom of the slab and a rubber-covered bar at the top, which was removed to form the sealing groove.[3]

The Tests

When the experiments were planned it was intended at one site to compare the surface finishes after the concrete had been spread by each of three different types of machine in front of each of three types of finishing machine. Unfortunately, suitable machines were impossible to obtain at the time and a blade-type spreading machine had to be used for all the work at Site 1 and a hopper-type for the whole length at Site 2. Direct comparisons of the effect of the type of spreading machine were therefore impossible, but the difficulties associated with each of these two types were investigated. A screw spreader could not be obtained for either experiment but it is considered that the result of using it would be similar to that of using a blade, since the concrete must be dumped on the subgrade in front of either machine in a similar way.

Two similar finishing machines with beams and screeds freely supported on wire ropes were used at Site 1. At Site 2, a direct comparison was made between the effect of this type of machine and that of one which had the beam and screed rigidly mounted between springs and rubber bushes. These machines were not fitted with a separate finishing beam, the surface being finished by the vibrating beams which were fitted with quarter-elliptical shoes. Horizontally oscillating screeds were fitted to the front of the machines and these could be used, in the first pass, to correct any errors in the amount of surcharge left by the spreading machine and, in the finishing pass, to attempt to remove any irregularities in the surface. A suitable machine with a separate finishing screed could not be obtained for either site, but experience was gained in the use, for finishing, of the oscillating screeds of the machines available, and it is not considered that a separate finishing screed would lead to any improvement. In the machine with the freely supported beam and screed (machine F) the screed rested on the tops of the forms in the finishing pass; the average amplitude of vibration was 0·02 inch at a frequency of 3,000 vibrations per minute. In the machine with a rigidly mounted beam and screed (machine R) the average amplitude of vibration was generally 0·02 inch at a frequency of 3,300 vibrations per minute. With this machine it was possible to alter the amplitude of vibration.

The following tests were made :—

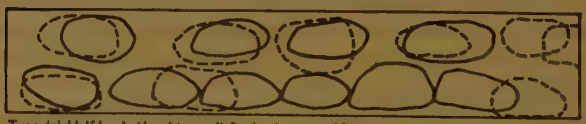
Spreading with the reciprocating-blade machine.—For most of the work the concrete was dumped from the lorries over the side forms, and the heaps were of necessity either full-loads (2 cubic yards) or half-loads (approximately 1 cubic yard). These were dumped either irregularly or in evenly spaced heaps, generally from one side of the lane, but for one section where

the verges were sufficiently wide the concrete was dumped from both sides. Elsewhere 2-cubic-yard heaps were necessary in order to provide sufficient concrete for the bottom course, or the lorries had to be run on the subgrade to dump the load for the bottom course across the bay. With the particular lorries available it proved impossible to use them to help in spreading the concrete by drawing them forward as tipping proceeded, and the concrete

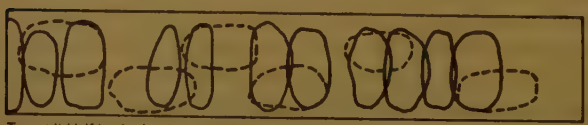
Figs 1

Type (a) Full loads (2 cubic yards) for both top and bottom courses in unevenly spaced heaps from one side of the lane

Type (b) Full loads (2 cubic yards) for the bottom and half loads for the top course in fairly evenly spaced heaps from one side of the lane



Type (c) Half loads (1 cubic yard) for both top and bottom courses in fairly evenly spaced heaps from both sides of the lane



Type (d) Half loads (1 cubic yard) for the bottom course in heaps across the bay and half loads for the top course in fairly evenly spaced heaps from both sides of the lane

The heaps for the bottom course are indicated by full lines and those for the top course by broken lines Full loads are hatched

THE METHODS OF SPREADING THE CONCRETE WITH THE BLADE SPREADER

had always to be dumped in heaps. The methods used are shown diagrammatically in *Figs 1*, and were :—

(*a*) 2-cubic-yard loads for both courses from one side of the lane.

(*b*) 2-cubic-yard loads for the bottom and 1-cubic yard loads for the top course from one side of the lane.

(*c*) 1-cubic-yard loads for both courses from both sides of the lane.

(*d*) 1-cubic-yard loads at intervals across the slab for the bottom course, and from both sides of the lane for the top course.

Spreading with the hopper machine.—The machine was originally designed for loading with side-tipping lorries but it was found to be more convenient and to lead to less irregularity if the Paver bucket was used to load the hopper directly as shown in *Fig. 2* (facing p. 670). Using this method of filling, loads of 2 cubic yards, which were sufficient to fill the hopper, were compared with loads of 1 cubic yard, which were small enough to be spread in one transverse movement, and with loads of ½ cubic yard spread from both edges towards the centre of the slab (this method gave the practical minimum amount of concrete in the hopper). Unfortunately, in practice it was found that the machine lacked sufficient power to handle loads of 2 cubic yards regularly and for most of the work 1½-cubic-yard loads were the maximum permitted.

In order to reduce any precompaction caused by the load in the hopper an inverted-V separating-plate was fitted along the centre in the original machine. In an attempt to reduce any such effect still further, hydraulically operated bottom doors were substituted for the inverted-V for some tests and for others a second pass was made with a loaded hopper over the concrete which had already been spread. The hopper was also moved in a transverse, diagonal, or longitudinal direction, these methods of operation being shown for typical slabs in *Figs 3*.

The design of the finishing machine.—The finish produced when the beam and screed were freely supported (machine F) was compared with that when they were rigidly mounted (machine R). Observation of machine F suggested that the removal of irregularities depended to some extent on the weight of the screed being sufficient to keep it in contact with the forms, and at Site 1 a load of 500 lb. was added for some sections while at Site 2 this was increased for a short length to 1,000 lb. When the two different machines were used in tandem at Site 2, the amplitude of the rigidly mounted vibrating beam was reduced for finishing to ½ and ¼ of its usual value.

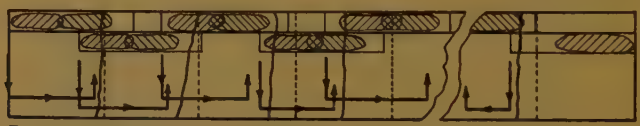
The method of operating the finishing machine.—In order to be certain of full compaction over the whole slab the surcharge was fixed at 1½ inch at Site 2. This surcharge was sufficient for the lowest points in the surface to be at form level after compaction and any levelling was obtained by removing surplus material. To reduce the amount of heavy work during the finishing process which this entailed, the effect of reducing the surcharge to 1¼ inch was examined. The effect of the time at which the surface irregularity was checked and the effect of stoppages in the work were also measured.

For several sections at both sites the workability of the concrete was increased, the compacting factor being raised from 0·79–0·80 to about 0·84 by increasing the water/cement ratio by about 0·05. At Site 1 this

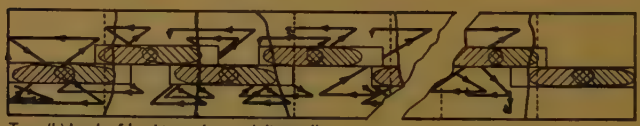
increase was made both on a level stretch and where there was a steep crossfall.

The alignment of the formwork.—The regularity with which the forms could be set was measured, and the alignment of the rails when set by normal boning was compared with that when they were levelled with a

Figs 3



Type (a) Loads of 1 cubic yard spread transversely



Type (b) Loads of 1 cubic yard spread diagonally

Type (c) Loads of 1 cubic yard spread longitudinally

Type (d) Loads of 1½ cubic yard spread transversely with loads of 1 cubic yard passed over the spread concrete

Top and bottom courses spread similarly Loads are hatched except for the loads of 1 cubic yard in type (d) The areas spread by each load are indicated by arrows and lines across the slab

THE METHODS OF SPREADING THE CONCRETE WITH THE HOPPER SPREADER

stretched line. The movements occurring under the machines at rail joints and the settlement during their passage was measured.

Joints.—The irregularities at expansion joints were compared with those at dummy joints and stop-ends.

Methods of Measurement

Concrete quality.—The quality of the concrete was generally controlled by measurements of its workability, using the compacting factor test.[4] In order to assess the amount of water to be added at the mixer, determinations were made of the moisture in each of the aggregates at the beginning

of each day's work. Thereafter, compacting factor tests were made on at least two samples of concrete from each slab, one taken from the bottom and one from the top course, and the amount of added water was altered during the day in order to keep the compacting factor as constant as possible. This system was satisfactory when reasonably large stockpiles of aggregate were maintained, but when this was not done, rapid fluctuations occurred in the moisture content and it then became necessary to supplement the workability tests on the concrete by more frequent determinations of moisture content in the aggregate. Moisture contents were then measured by pycnometer and the amount of water added at the mixer altered in the light of the moisture content and the trend of the compacting factors, in order to keep the compacting factor as constant as possible. At both sites the samples for compacting-factor tests were taken from the concrete deposited on the subgrade, and at Site 1 this was up to 2 miles from the mixer so that there was some delay in making alterations to the mix, whilst at Site 2, where the mixer was always close at hand, there was little delay. The improved standard of control achieved at Site 2, which has already been mentioned, was attributed to the speed with which the mix could be adjusted. In some of the tests to examine the effect of the workability of the concrete, compacting-factor tests were made on a sample from each load of concrete as it was delivered to the work in order to give improved control. After the compacting-factor tests had been made some samples were used to make one 6-inch cube, which was tested for compressive strength when 28 days old.

Surface finish.—The riding quality of the finished surface was checked by means of the multi-wheel profilometer [1] developed at the Road Research Laboratory. This machine, however, can be used only to measure the surface irregularity after the concrete has hardened, and it was considered desirable to have some means of assessing the quality of the surface while the concrete was still sufficiently plastic for improvements to be made. For this purpose a " wet-surface profilometer " as shown in *Fig. 4* (facing p. 670) was designed; it consisted essentially of a rigid frame having the same wheel base as the finishing machine. The frame carried two recording wheels in the same position relative to the chassis wheels as that occupied by the trailing edge of the vibrating beam of the finisher, the wheels being 2 feet 9 inches from the edges of the slab. The recording wheels were counter-balanced so that the pressure on the concrete was only just sufficient to rotate the wheels, and their vertical movements were recorded on rolls of paper driven through a 60-to-1 reduction-gear by a wheel running on the forms. The profilometer was generally towed by the finishing machine when only one was being used, and was pushed by the second machine when two were being used in tandem, so that it was possible to get a record of the surface after the first pass. With this arrangement, irregularities in form setting are not reproduced in the record and a horizontal line would indicate that the finishing machine has produced the best surface possible,

Fig. 5

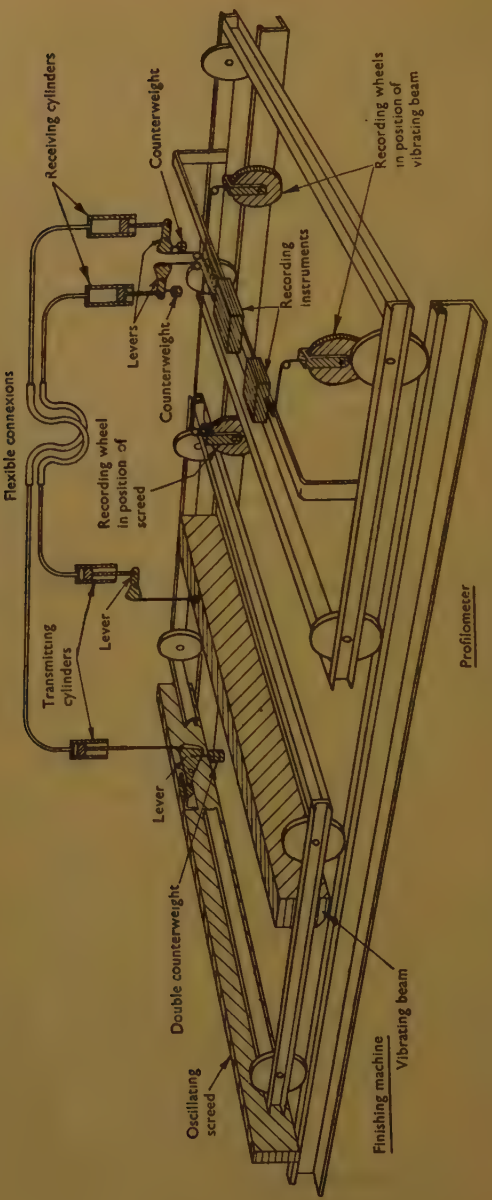


DIAGRAM OF PROFILOMETER MODIFIED TO RECORD MOVEMENTS OF THE SCREED AND BEAM OF THE FINISHING MACHINE AS WELL AS THE IRREGULARITY OF THE SURFACE

whilst any departure from this line would indicate an irregularity which might be corrected by further passes of the finishing machine.

For a few tests the wet-surface profilometer was modified to give records of the rise and fall of the oscillating screed and vibrating beam of the finishing machine to which it was attached, as well as of the irregularities in the surface. Since, in order to avoid the transmission of any vibrations, the profilometer was not attached rigidly to the finishing machine, the movements of the screed and beam were transmitted hydraulically to the recording instrument on the profilometer, flexible pipes being used between the two machines. The arrangement, shown diagrammatically in *Fig. 5*, consisted of a lever which was depressed when the screed or beam was lowered and which transmitted the movement to a piston in a sealed system filled with very thin oil. This operated a similar piston and lever on the profilometer. The modified frame also carried a recording wheel 2 feet 9 inches from one side of the slab in the same position relative to the chassis as the trailing edge of the oscillating screed, in addition to the two original wheels recording irregularities in the position of the vibrating beam. The records of the screed and beam were also taken 2 feet 9 inches from this side of the slab, and the four records in this position were recorded on the same paper in the instrument shown in *Fig. 6* (between pp. 670 and 671).

The skidding resistance [5] of selected lengths of the finished road was measured by means of the skidding motorcycle, the surface of the concrete being swept and sprayed with water before the tests were made. It is proposed to repeat these tests after the roads have been open to traffic for some time.

Form setting.—The accuracy of the form and rail setting was measured by means of a microptic level and a staff divided in millimetres. For short lengths the actual movements of the rails and forms under the machines were measured by the gauges shown in *Fig. 7*. These consisted of a lever with a hemispherical contact point at one end which was placed against the underside of the rail. A bronze point at the other end of the lever was kept in contact with a sensitized paper by means of a spring. The lever magnified the movement eight times, and by moving the paper a record was obtained of the movement during the passage of each wheel of each machine. Each gauge was carefully set level on a prepared patch of the subgrade before each test.

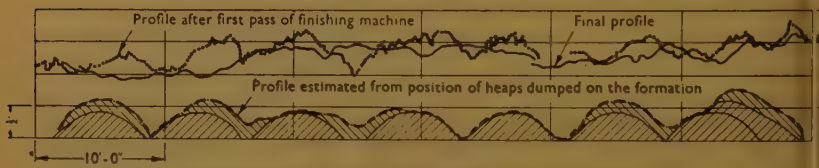
The Method of Spreading the Concrete

The Reciprocating-Blade Machine

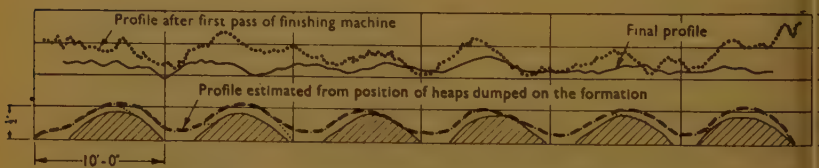
The size of the load.—The records given by the wet-surface profilometer for typical slabs laid using heaps of different sizes are shown in *Figs 8*. Where the concrete was dumped on one side of the slab the record for that side, which in all cases showed more irregularity, has been reproduced so

that the effect of the position of the heaps could be analysed. The results show that after the first pass of the finishing machine most irregularity occurred when full loads of about 2 cubic yards were dumped for both courses (*Fig. 8* (*a*)). There was some slight improvement when half-loads were used for the top course (*Fig. 8* (*b*)), but it was necessary to use half-loads for both courses before a marked improvement was obtained (*Fig. 8*

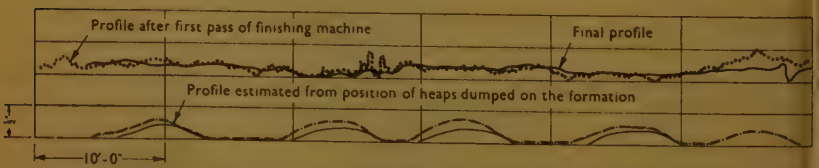
Figs 8


Profile after first pass of finishing machine
Final profile
Profile estimated from position of heaps dumped on the formation
10'-0"

Type (a) Full loads (2 cubic yards) for both top and bottom courses in unevenly spaced heaps from one side of the lane


Profile after first pass of finishing machine
Final profile
Profile estimated from position of heaps dumped on the formation
10'-0"

Type (b) Full loads (2 cubic yards) for the bottom and half loads for the top course in fairly evenly spaced heaps from one side of the lane


Profile after first pass of finishing machine
Final profile
Profile estimated from position of heaps dumped on the formation
10'-0"

Type (c) Half loads (1 cubic yard) for both top and bottom courses in fairly evenly spaced heaps from both sides of the lane

THE EFFECT ON THE SURFACE OF THE SIZE OF THE HEAP OF CONCRETE IN FRONT OF THE BLADE SPREADING MACHINE

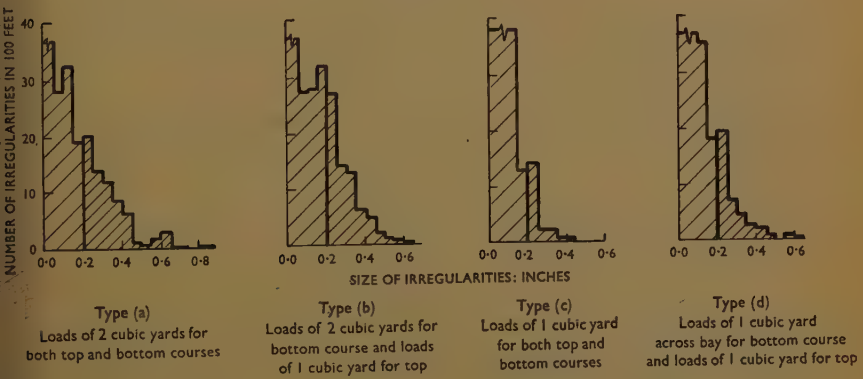
Note: The heaps for the bottom course are indicated by full lines and those for the top course by broken lines. Full loads are hatched.

(*c*)). In order to obtain a quantitative estimate of the unevenness at this stage, the profiles were scaled off in 5-foot intervals, and a straight edge of a length equivalent to 10 feet was placed on the record so that it just touched the two highest points on the profile beneath it. The distance between the scale and the record was then measured at 1-foot intervals. This was repeated for a length of 100 feet with the 10-foot straight edge moved along

the record 5 feet and again placed on the two highest points on this section. Three 100-foot lengths were measured separately for each type of spreading but there was little variation between the results for the three lengths and only the average figures were used to obtain the histograms shown in *Figs 9*. Since it was considered that a road with good riding quality could be obtained by a specification requiring that no irregularity should be greater than $\frac{3}{16}$ inch in 10 feet the irregularities greater than 0·2 have been emphasized in the figure. This confirms that it was necessary to use 1-cubic-yard loads for both courses before any noticeable improvement was obtained.

The profile which might be expected after the first pass was estimated from the positions of the heaps, on the assumption that all the irregularities

Figs 9


NUMBER OF IRREGULARITIES IN 100 FEET
40
30
20
10
0
0·0 0·2 0·4 0·6 0·8
0·0 0·2 0·4 0·6
0·0 0·2 0·4 0·6
0·0 0·2 0·4 0·6
SIZE OF IRREGULARITIES: INCHES
Type (a)
Loads of 2 cubic yards for both top and bottom courses
Type (b)
Loads of 2 cubic yards for bottom course and loads of 1 cubic yard for top
Type (c)
Loads of 1 cubic yard for both top and bottom courses
Type (d)
Loads of 1 cubic yard across bay for bottom course and loads of 1 cubic yard for top

THE SIZE AND NUMBER OF THE IRREGULARITIES GIVEN BY THE BLADE SPREADING MACHINE AFTER THE FIRST PASS WITH THE VIBRATOR

in the surface were related to the degree of precompaction which was, in turn, related to the method of dumping the concrete. It was considered reasonable to suppose that the dumping of a load of 2 cubic yards would produce about twice the amount of precompaction, and hence twice the effect on surface irregularity, as a load of 1 cubic yard. Also, since at Site 1 the bottom course was spread to about twice the depth of the top course ($6\frac{1}{2}$ inches and 3 inches respectively), and since the dumping of the top course would not be likely to cause much further compaction of the bottom course, because of the supporting effect of the layer of reinforcement, the effect of a heap in the bottom course would be double that of one in the top course. The profiles estimated in this way are shown in *Figs 8*. They compare very well with those given by the wet-surface profilometer after the first pass of the machine, thus suggesting that the size of the heaps of concrete in front of the spreading machine was the chief cause of the initial irregularity.

The profiles after the final pass of the finishing machine are also given in *Figs 8*. Some of the bumps present originally were reduced in size by repeated passes of the machine and adjacent ones coalesced, but although the finishing process was continued until there was considerable danger of tearing the surface, all the initial irregularity was not removed. The results of the tests with the multi-wheel profilometer, given in Table 1, confirm that the initial unevenness persisted and affected the final surface. The best surface was obtained when heaps of about 1 cubic yard were dumped evenly from both sides of the lane for both the top and bottom layers of concrete. When the heaps were dumped less carefully and on one side of the lane only, the irregularity was much greater in the line of the heaps than on the side of the lane remote from the heaps (that is, on the side to which the concrete was pushed by the spreading machine). When there was considerable initial irregularity, therefore, the riding quality of the finished surface was poor; it appears to be essential to control the spreading carefully.

TABLE 1.—THE EFFECT ON THE FINAL SURFACE OF THE METHOD OF SPREADING THE CONCRETE WITH THE BLADE SPREADER

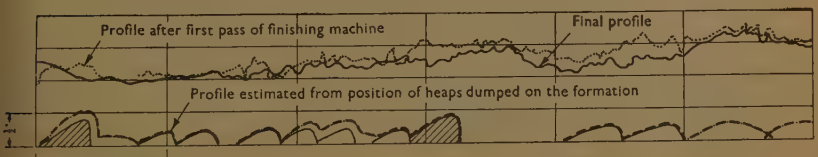
Location	Position of centre of heap of concrete	Irregularity index: inches per mile 2′-9″ from edge	2′-9″ from centre line	Remarks
(*a*) Full loads of 2 cubic yards for both top and bottom courses				
480 feet in first lane	3 feet from edge	184	95	Profilometer behind second finishing machine
420 feet in second lane	4 feet from centre line	68	88	Profilometer between the two finishing machines.
(*b*) Full loads of 2 cubic yards for the bottom and half loads of 1 cubic yard for the top course				
630 feet in first lane	3 feet from edge	124	86	Profilometer behind second finishing machine
300 feet in first lane	3 feet from edge	108	71	Profilometer behind second finishing machine
360 feet in second lane	4 feet from centre line	64	80	Profilometer between the two finishing machines
(*c*) Half loads of 1 cubic yard for both top and bottom courses				
360 feet in first lane	3 feet from both edge and centre line	63	77	Profilometer between the two finishing machines

The method of operating the machine.—The profiles for the section where 1-cubic-yard loads were dumped for the bottom course in heaps across the bay and for the top course from both sides are given in *Fig. 10* and the

histogram of the irregularities in *Figs 9*. Unfortunately, the method resulted in twice as many heaps in each wheel track and hence in twice as many bumps—each bump being of shorter length, and the profile after the first pass of the finishing machine was only a little better than that when 2-cubic-yard loads had been used for the bottom course (*Figs 8* (*b*)). Since running the lorries on the subgrade complicated the operations it was not considered to be justified by the very small improvement obtained.

When heaps have to be placed close together, owing to all the loads being dumped on one side of the slab, however, they should be carefully spaced. Although little segregation was noticeable in most of the heaps, the higher percentage of coarse aggregate at the edges persisted during

Fig. 10


Profile after first pass of finishing machine
Final profile
Profile estimated from position of heaps dumped on the formation
10'-0"

Type (d) Half loads (1 cubic yard) for the bottom course in heaps across the bay and half loads for the top course in fairly evenly spaced heaps from both sides of the lane

THE EFFECT ON THE SURFACE OF THE METHOD OF PLACING THE HEAPS OF CONCRETE IN FRONT OF THE BLADE SPREADING MACHINE

Note: The heaps for the bottom course are indicated by full lines and those for the top course by broken lines. Full loads are hatched.

spreading and compaction and resulted in honeycombing at the bottom of the slab where the heaps overlapped. A selection of cores drilled where the edges of two heaps of dumped concrete came together is shown in *Figs 11* (between pp. 670 and 671), together with some from corresponding positions on the other side of the lane where the concrete had been spread by the machine. The effect was much less noticeable when the heaps of concrete were spread across the slab since, where the heaps merged, there was generally a high proportion of fines in one and of coarse aggregate in the other.

Some of the cores were tested; the strengths are given in Table 2, together with the 28-day strength of the cubes taken from the same slab. The effect of segregation on the concrete strength is shown clearly by the results. When the cores were taken from where the edges of heaps of dumped concrete came together the cube strength was about 1·5 times the core stress, but when the cores were taken from where the concrete was spread by the machine the difference in strength was reduced, the average ratio being about $\frac{4}{3}$ (the figure given for fully compacted concrete in British Standard 1881).

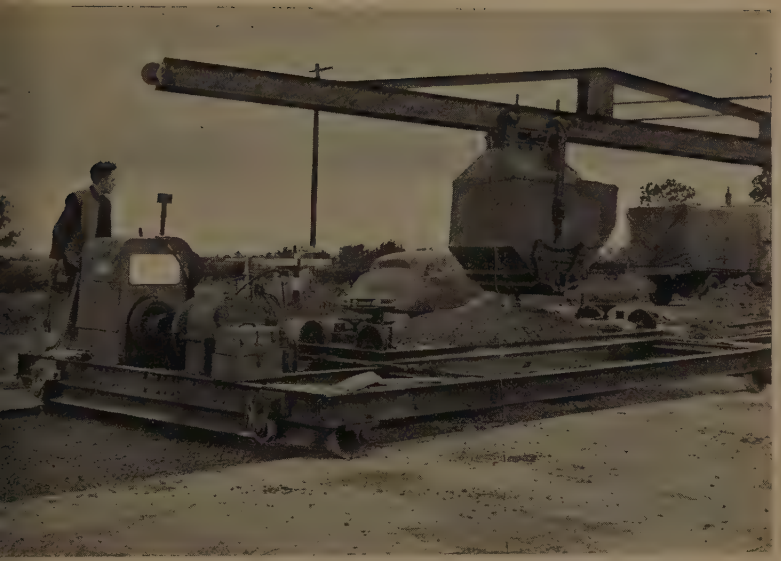
Also, when all the concrete is dumped from one side of the lane the

TABLE 2.—RESULTS OF TESTS ON CORES TAKEN FROM BETWEEN HEAPS AND FROM CONCRETE SPREAD BY THE MACHINE

Core Number	Compaction	Approx. 28-day core stress: lb. per sq. inch	Strength of cube from the same slab at 28 days: lb. per sq. inch	Ratio of cube to core stress	Average ratio of cube to core stress
(*a*) Cores taken where the edges of two heaps overlapped					
1	Fair to 7 inches. Honeycombed below. Many small voids throughout	4,800	7,100	1·48	
3	Well compacted throughout except for few small voids	5,250	7,800	1·49	
5	Good throughout	4,570	7,350	1·60	1·50
7	Good throughout	5,550	7,800	1·41	
9	Very good throughout	4,950	7,500	1·52	
(*b*) Cores taken from concrete spread by the machine					
2	Very well compacted, few voids ½ inch from bottom	4,800	5,800	1·20	
4	Well compacted throughout. Surface crack about ½ inch deep	5,400	7,800	1·44	
6	Good to 4 inches. Few medium and small voids below	6,150	7,350	1·20	1·31
8	Well compacted throughout except for some scattered small voids	5,550	7,700	1·40	
10	Compaction good throughout. Some small voids	5,800	7,500	1·29	

density of the spread concrete on that side will be greater than that on the other, and in order to obtain the same density in the compacted concrete it is necessary to give more surcharge on the side opposite to the dumping. This was done for most of the work when the concrete was spread from one side of the 8-inch-thick slab by tilting the screeds of the spreading and compacting machines to give a surcharge of 1½ inch on the side where the heaps were tipped, and 2 inches on the other. The results of tests on cores are given in Table 3. When the screeds were level the strength of the core

Fig. 2



Loading the Hopper Spreading Machine from the Paver

Fig. 4

The Wet-Surface Profilometer

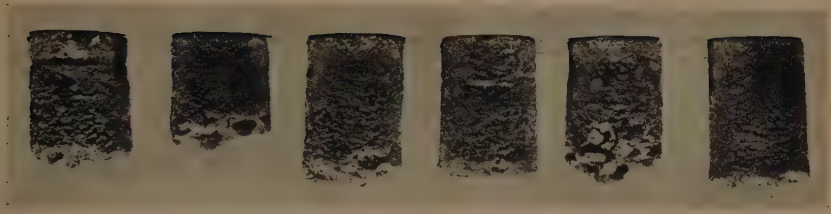
Fig. 6

THE INSTRUMENT FOR RECORDING THE MOVEMENT OF THE SCREED AND BEAM OF T
FINISHING MACHINE AND THE UNEVENNESS OF THE SURFACE OF THE CONCRETE

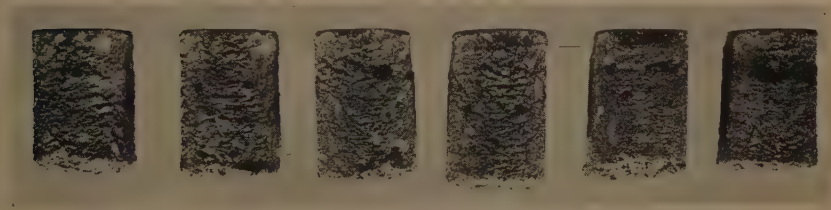
Fig. 7

GAUGES FOR MEASURING THE MOVEMENTS OF THE RAILS

Figs 11



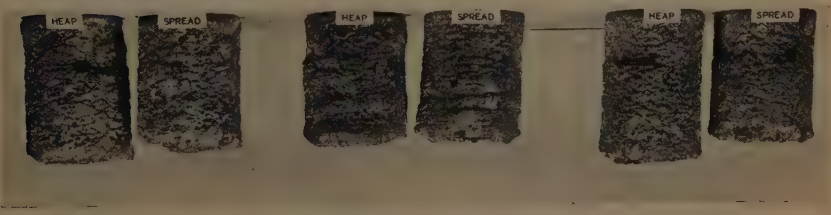
Cores cut where the edges of two heaps of dumped concrete came together
(Bad honeycombing at the base of some of these cores)



Cores cut from the concrete spread by the blade spreading machine on the other side of the lane. (Good compaction)

THE EFFECT OF THE SPREADING OF THE CONCRETE ON ITS COMPACTION

Figs 20



COMPACTING FACTOR 0·79 (GOOD COMPACTION)

COMPACTING FACTOR 0·84

(Some honeycombing near the base of some of these cores)

The cores marked "heap" were cut from places where the centres of heaps of concrete were dumped during spreading, and those marked "spread" were cut from places where the concrete was spread by the machine

THE EFFECT OF THE WORKABILITY OF THE CONCRETE ON COMPACTION

Fig. 21

THE SEGREGATION OF A WET MIX DURING TRANSPORT AND DISCHARGE FROM THE LORRY

TABLE 3.—RESULTS OF TESTS ON CORES TAKEN WHERE THE SCREEDS OF THE MACHINES WERE TILTED OR LEVEL

Cores taken from line of dumps			Cores taken from spread concrete			Ratio of strength of spread concrete to strength of dumped concrete
Core number	Compaction	Approx. 28-day core stress: lb. per sq. inch	Core number	Compaction	Approx. 28-day core stress: lb. per sq. inch	
Screed level						
2	Very well compacted; few voids ½ inch from bottom	4,800	11	Compaction good to 6½ inches, one or two voids above	3,150	0·66
10	Compaction good throughout. Some small voids	5,800	12	Compaction fairly good above 7½ inches, but with some voids	4,950	0·85
Screed tilted to give ½ inch extra surcharge where the concrete was spread by the machine						
13	Very well compacted; few voids ½ inch from bottom	4,800	14	Compaction good; few voids	5,250	1·09
15	Compaction fair, many voids 1½ inch from top and some segration 2½ inches from bottom	4,420	16	Compaction good; honeycombed at bottom and some small voids above	4,720	1·06

cut from the side to which the concrete was spread by the machine was considerably less than that of the corresponding one, but after the screeds had been tilted the strength in the line of the heaps was somewhat less than that on the spread side. It seems that the difference in surcharge was a little too great, and that better results would have been obtained by tilting the screed by ⅜ inch instead of by ½ inch. The results do emphasize, however, the importance of uniform spreading for full compaction.

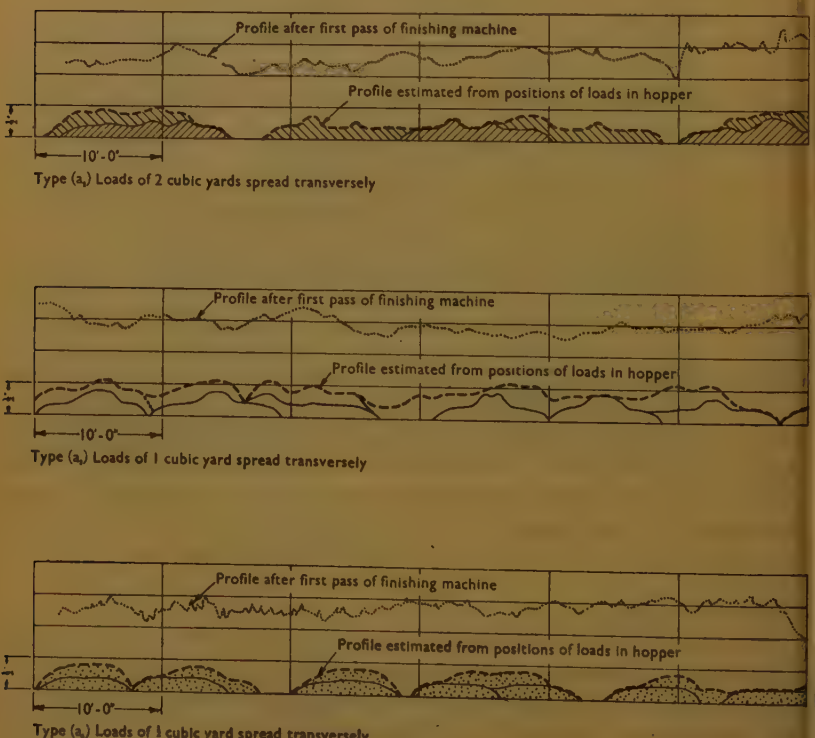
The Hopper Machine

The size of the load.—The profiles were taken by the wet-surface profilometer 2 feet 9 inches from both edges of the slabs, but since, in most cases, after the first pass of the finishing machine the records were almost identical only one has been considered. A comparison of the records when loads of different sizes were used, which are given in *Fig. 12*, shows that the size of the irregularity tends to increase with the size of the load, but that the number of bumps per unit length tends to be inversely proportional to it.

In a similar manner to that used previously an attempt has been made

to estimate the profile after the initial compaction on the assumption that all the irregularities in the surface are related to the degree of precompaction caused by the method of spreading the concrete. Unfortunately, the Paver bucket would not hold a complete cubic yard of the very dry mix and the hopper was filled with one or more ½-yard heaps, the bucket and hopper being moved together so that the heaps were spread fairly evenly in the hopper. The position of each ½-cubic-yard load was recorded, and the profiles estimated from them are shown in *Figs 12*. The agreement between the estimated and the actual profiles is not so good as that obtained when the concrete was dumped directly on the subgrade, but there is a general resemblance. With this type of spreading machine exact agreement was not expected since the concrete did not always fall freely out of the hopper. When there was some arch action in the bottom of the hopper the weight of the concrete remaining would have little effect on the material

Figs 12

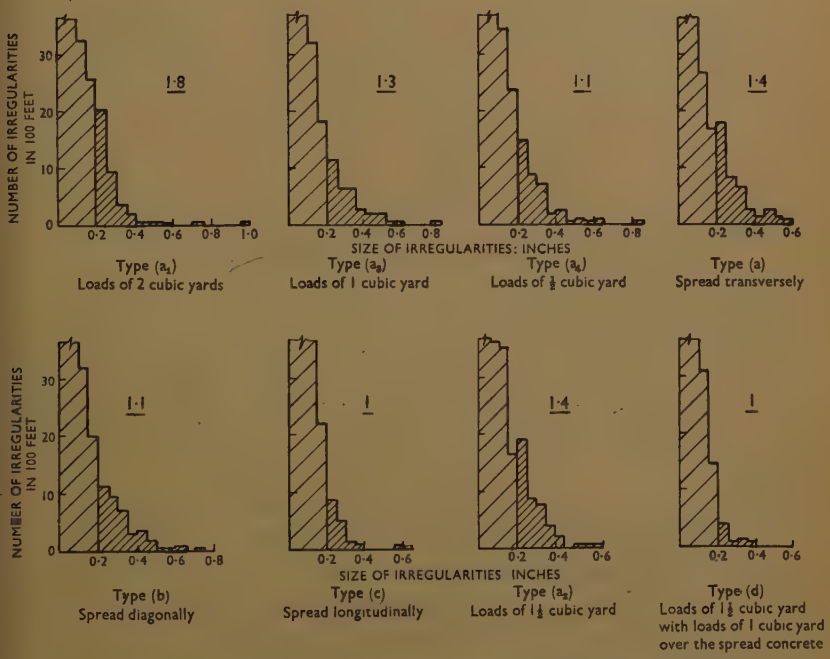

Profile after first pass of finishing machine
Profile estimated from positions of loads in hopper
10'-0"
Type (a_2) Loads of 2 cubic yards spread transversely
Profile after first pass of finishing machine
Profile estimated from positions of loads in hopper
10'-0"
Type (a_1) Loads of 1 cubic yard spread transversely
Profile after first pass of finishing machine
Profile estimated from positions of loads in hopper
10'-0"
Type (a_1) Loads of 1 cubic yard spread transversely

THE EFFECT ON THE SURFACE OF THE SIZE OF THE LOAD IN THE HOPPER

Note: The heaps for the bottom course are indicated by full lines and those for the top course by broken lines. Loads of 2 cubic yards are hatched and the loads of ½ cubic yard are stippled.

already spread, but when the concrete was falling freely its weight would necessarily be supported by the spread concrete. This variation in the behaviour of the concrete was a general difficulty at this site and the lack of close agreement between the actual and estimated profiles has been attributed to it, but there is sufficient evidence to show that a freely falling load in the hopper causes some precompaction which results in surface irregularity.

Figs 13


NUMBER OF IRREGULARITIES IN 100 FEET
1·8
1·3
1·1
1·4
SIZE OF IRREGULARITIES: INCHES
Type (a_1) Loads of 2 cubic yards
Type (a_2) Loads of 1 cubic yard
Type (a_3) Loads of ½ cubic yard
Type (a) Spread transversely
1·1
1
1·4
1
Type (b) Spread diagonally
Type (c) Spread longitudinally
Type (a_4) Loads of 1½ cubic yard
Type (d) Loads of 1½ cubic yard with loads of 1 cubic yard over the spread concrete

THE SIZE AND NUMBER OF THE IRREGULARITIES GIVEN BY THE HOPPER-TYPE SPREADING MACHINE AFTER THE FIRST PASS WITH THE VIBRATOR

The profiles after the final pass of the finishing machine are not given in the figures since the specification required that every effort should be made to remove any irregularities greater than $\frac{3}{16}$ inch in a 10-foot length, and the number of finishing passes of the vibrator necessarily varied. For the same reason the results of the tests with the multi-wheel profilometer which are given in Table 4, where sections treated similarly in other respects are given in the same row, do not show clearly any effect due to the size of the load in the hopper. In fact, the most even surface seems to have been produced when 2-cubic-yard loads were used. The histograms of the number and size of the irregularities measured under a 10-foot straight edge after

TABLE 4.—THE EFFECT ON THE FINAL SURFACE OF THE METHOD OF SPREADING THE CONCRETE WITH THE HOPPER SPREADER

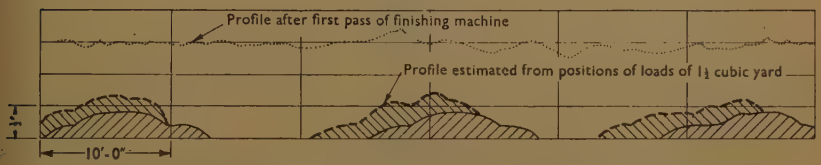
Effect examined	Length: feet	Irregularity index : inches per mile		Length: feet	Irregularity index : inches per mile		Length: feet	Irregularity index : inches per mile	
		High side	Low side		High side	Low side		High side	Low side
	(a_1) Spreading machine loaded with 2 cubic yards			(a_3) Spreading machine loaded with 1 cubic yard			(a_4) Spreading machine loaded with ½ cubic yard		
Size of load	400	63	72	450	69	90			
	300	70	61	450	74	83			
				450	80	76			
				750	79	98			
				300	116	113			
				300	66	94	300	82	90
				500	79	81	300	77	88
	(a_5) Spreading machine without bottom doors			(a_6) Spreading machine fitted with bottom doors					
Use of bottom doors to hopper	450	69	90	500	79	81			
	300	57	79	400	82	67			
	500	65	72	300	66	94			
	500	93	109	400	91	81			
	(a) Spreading machine operated transversely			(b) Spreading machine operated diagonally			(c) Spreading machine operated longitudinally		
Direction of operation of hopper	450	69	90	450	74	83	300	83	87
				450	80	76			
				750	79	98			
				300	116	113			
	300	57	79	300	83	117			
	500	65	72						
	500	81	82	500	74	97			
	(a_2) Spreading machine loaded with 1½ cubic yard			(d) Spreading machine loaded with 1½ cubic yard and later with 1 cubic yard to be moved over the spread concrete					
Use of second pass of loaded hopper	500	68	108	400	60	79			
	400	113	92	300	88	76			

the pass of the vibrator are given in *Figs 13*, together with the average number of finishing passes for each section. There was little difference in the initial irregularity, the more even surface when 2-cubic-yard loads were used being attributable to the care which was taken in finishing.

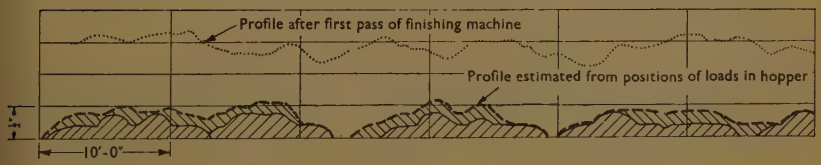
The Method of Operating the Machine

The profiles given in *Figs 14* show that after the first pass of the finishing machine the irregularity of the surface was closely connected to the method of operating the spreader. There was little difference between the surfaces when either transverse or diagonal spreading was used and the profile given

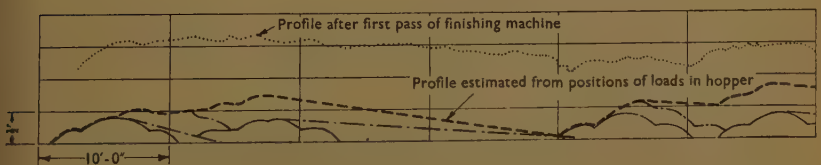
Figs 14



Type (d) Loads of 1½ cubic yard spread transversely with loads of 1 cubic yard passed over the spread concrete



Type (a_2) Loads 1½ cubic yard spread transversely



Type (c) Loads of 1 cubic yard spread longitudinally

THE EFFECT OF THE METHOD OF OPERATING THE HOPPER SPREADING MACHINE

Note: The loads for the bottom course are indicated by full lines, those for the top course by broken lines, and the decrease in the load when longitudinal spreading was used by chain-dotted lines. Loads of 1½ cubic yards are hatched.

by the latter has not been reproduced, but the number of bumps was reduced by longitudinal spreading. The greatest improvement, however, was obtained when a full hopper of concrete was moved over the surface of the spread concrete, the size of the irregularities being markedly reduced. The bottom doors fitted to the hopper enabled the concrete to be transported to any position before it was deposited but had little effect on the surface.

The agreement between the profile after the first pass of the finishing machine and that estimated from the records of the spreading was most marked when longitudinal spreading was used; large bumps occurred where the hopper was loaded but gradually faded out as the load was spread. The general position of the loads also showed in the profile when the load was spread transversely, but when a fully loaded hopper was passed over the surface of the spread concrete the profile after the first pass of the finishing machine showed little evidence of the positions of the bumps which would have been expected from normal spreading. This profile estimated from normal spreading is shown in *Figs 14*, from which the amount of improvement obtained by the extra passes of the spreading machine can be estimated.

The results of the tests with the multi-wheel profilometer given in Table 4, confirm that the best surface was obtained when a hopper full of concrete was moved over the whole surface of the spread concrete for both the top and bottom of a 400-foot-long section. When a similar method of spreading was used for a 300-foot-long section for which, in order to save time, the extra loaded pass of the spreading machine was made over the top course only, the results were not so good. Irregularities in spreading in the bottom course do not appear to have been corrected by the pass over the top course, probably because of the presence of the reinforcement. The method, therefore, requires an extra pass of the spreading machine for each course and consequently causes some delay. Further, during the extra pass concrete is pushed over the side of the forms which makes it more difficult to keep the rails clean, and for these reasons this method of spreading cannot be accepted as completely satisfactory in practice. When no attempt was made to compensate for irregularities by an extra pass of the spreading machine the surface seemed to be slightly better when the concrete was spread transversely than when either diagonal or longitudinal movements were used.

The estimates of the irregularity of the surface after the first pass of the compacting machine and the average number of finishing passes made by the machine, given in *Figs 13*, emphasize the superiority of the spreading when the extra pass was made with the loaded spreader-hopper. The amount of the initial irregularity was much smaller and only one finishing pass was required in order to produce the most regular surface obtained during the tests. The slight superiority of operating the spreader transversely was, however, not substantiated. The difference between the sections was found to be due to extra effort in the finishing operation and not to the method of spreading. In fact, longitudinal movement of the spreader is to be preferred since the initial irregularity was smaller and since fewer finishing passes were considered to be necessary.

With the hopper spreading machine there appeared to be little segregation in the concrete. Cores were drilled in the finished slabs from various points chosen to show any tendency for there to be a higher proportion of

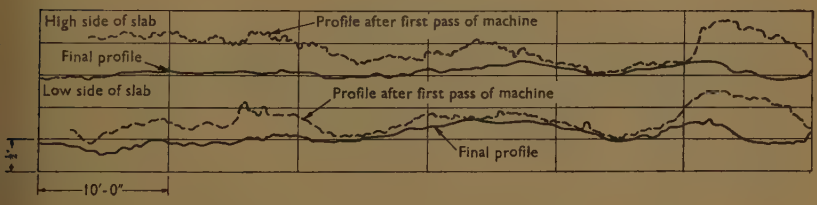
coarse aggregate than the nominal, for example, at the points where the hopper became empty, but the concrete was found to be uniform and fully compacted. This may of course be caused in part by the thinness of the slab (6 inches) but the large number of cores taken without any sign of poor compaction makes it unlikely that any segregation did occur.

The Method of Finishing the Surface

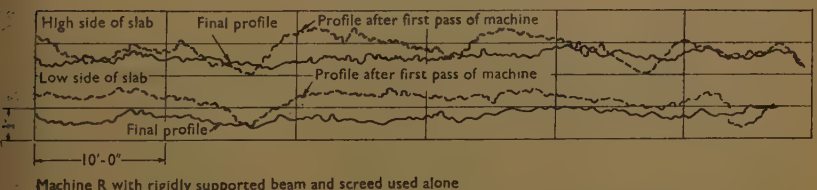
The Effect of the Design of the Machine

The method of supporting the beam and screed.—The results of the tests with the wet-surface profilometer on the sections laid with the two different finishing machines are given in *Figs 15*; in addition, Table 5, where

Figs 15



Machine F with freely supported beam and screed used alone



Machine R with rigidly supported beam and screed used alone

The Effect on the Surface of the Type of Finishing Machine

sections treated similarly in other respects are given in the same row, gives the results of tests with the multi-wheel profilometer and skidding motor-cycle. Contrary to expectation the surface produced by the machine with the rigidly mounted beam and screed (machine R) was not more regular than that obtained from the machine where they were freely supported (machine F). With the first machine there was no significant difference in regularity between the high and low sides of the slabs caused by the crossfall, but with machine F, the profile of the high side was obviously more even than that of the low side after the final pass, although after the first pass there was little difference. The high side of these slabs had in fact an average irregularity index of 23 inches per mile less than that of the low side and its value was also less than that of either side when machine

TABLE 5.—THE EFFECT ON THE EVENNESS OF THE FINAL SURFACE AND THE SKIDDING RESISTANCE OF THE METHOD OF FINISHING THE CONCRETE SPREAD BY THE HOPPER-TYPE MACHINE

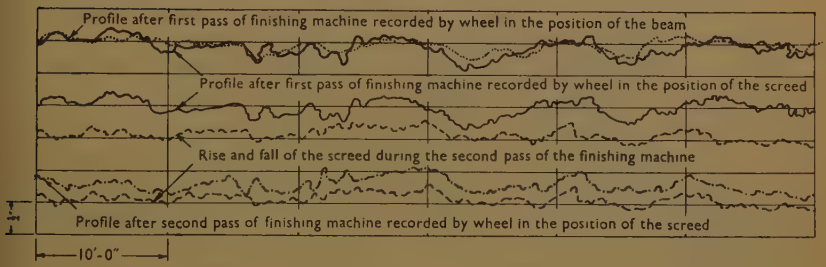
Size of load used in spreading: cubic yard	Machine F alone with 500 lb. of extra weight in the screed			Machine R alone			Machine F followed by machine R			Machine F followed by machine R with ½ its usual amplitude			Machine F followed by machine R with ¼ its usual amplitude			Remarks
	Irregularity index: inches per mile		Sideway force coefficient at 30 miles per hour	Irregularity index: inches per mile		Sideway force coefficient at 30 miles per hour	Irregularity index: inches per mile		Sideway force coefficient at 30 miles per hour	Irregularity index: inches per mile		Sideway force coefficient at 30 miles per hour	Irregularity index: inches per mile		Sideway force coefficient at 30 miles per hour	
	High side	Low side		High side	Low side		High side	Low side		High side	Low side		High side	Low side		
1½	68	108	0·60	113	92	0·64				67	86	0·43*				
	105	100		101	70											The surcharge for these slabs was reduced from 1½ inch to 1¼ inch
	65	98	0·64	83	79	0·7				64	69	0·54				The compacting factor for these slabs was increased from 0·82 to 0·84
1	66	94		79	81					91	81		113	174	0·40	
	57	79		69	70		81	82		93	109					
	83	117		74	83		74	97								
½	82	90		77	88											

* Owing to a breakdown at the batching plant this section was more workable than intended.

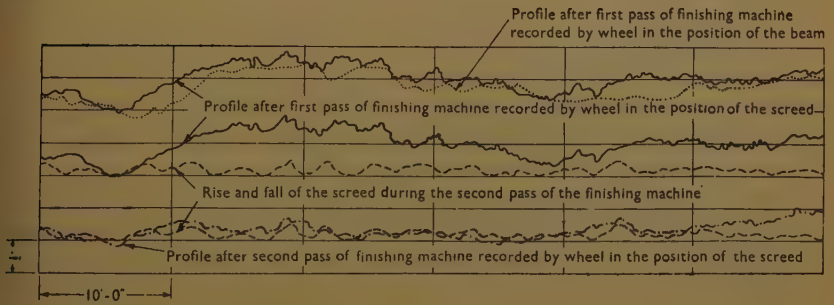
R was being used. This difference between the two final surfaces was caused by a number of bumps of about 0·1 or 0·2 inch height and about 3 or 4 feet length on the low side which did not appear on the high side. These small bumps have been attributed to flow of the concrete down the crossfall, which gives an excess of material on the low side and also makes it difficult to keep the running surfaces clean.

The records of the unevenness of the surface and of the rise and fall of

Figs 16


Profile after first pass of finishing machine recorded by wheel in the position of the beam
Profile after first pass of finishing machine recorded by wheel in the position of the screed
Rise and fall of the screed during the second pass of the finishing machine
Profile after second pass of finishing machine recorded by wheel in the position of the screed
10'-0"

About 500 lb. of extra weight added to the screed


Profile after first pass of finishing machine recorded by wheel in the position of the beam
Profile after first pass of finishing machine recorded by wheel in the position of the screed
Rise and fall of the screed during the second pass of the finishing machine
Profile after second pass of finishing machine recorded by wheel in the position of the screed
10'-0"

About 1,000 lb. of extra weight added to the screed

THE RISE AND FALL OF THE SCREED OF MACHINE F
(BEAM AND SCREED FREELY SUPPORTED)

the screed of machine F, which were obtained with the modified wet-surface profilometer, are given in *Figs 16*. The record for the vibrating beam is not reproduced since it showed no rise nor fall. The surface irregularity was, therefore, not affected by the vibrating beam which vibrates through the bumps, the concrete compressing under it and rising again behind it. The profiles of the surface were taken by two recording wheels in the same path; one was in the position of the trailing edge of the screed relative to the

chassis, and the other was in the usual position which is that of the trailing edge of the vibrating beam. The two records are similar, but there is some divergence due to irregularities in the formwork, the record given by the screed wheel being the more irregular since it was carried outside the wheel base. A comparison of the profile recorded by the screed wheel after the first pass and of the rise and fall of the screed during the second pass of the finisher shows that although the screed removed some of the bumps it often tended to follow the existing surface. Its movement was the main cause of the unevenness left by this second pass, the profile given by the screed wheel after this pass being almost identical. The regularity of the surface was therefore affected only by the oscillating screed and not at all by the vibrating beam.

When machine R was employed the records taken on the beam and screed both showed that there was no movement, as was to be expected from the method of mounting. The concrete in the bumps, therefore, must have moved under both the beam and the screed of this machine and risen behind them. The screed was much narrower than that of machine F; it was bull-nosed and was only 3 feet in front of the vibrating beam. In machine F there was a 5-foot clear distance between the 8½-inch-wide screed and the beam, so that the concrete under the screed was not likely to be affected by the vibrations. In machine R, however, it is possible that the vibrations were transmitted in front of the vibrator as far as the screed, and that this enabled the concrete to move under the narrow rounded section.

The weight of the screed.—The effect of increasing the weight of the oscillating screed by 500 lb. at Site 1, which is shown in Table 6 where similarly treated sections are again given in the same row, was to give a better surface to the side where the concrete was dumped. The average depth of concrete screeded-off during the finishing process amounted to as much as 0·31 inch whereas with the normal screed it was never more than 0·2 inch. In view of this result 500 lb. of extra weight was added throughout the second experiment, and for one short section this was increased to 1,000 lb. The records obtained with the modified wet-surface profilometer of the rise and fall of the screed and the profiles of the surface under these conditions are shown in *Figs 16*. With this very heavy screed there was much less tendency during the second pass for it to follow the irregularities of the existing surface, and the final profile was correspondingly improved. Unfortunately, this load was too much for the machine owing to the friction between the screed and the concrete surface of the first lane, and it could be used only for a limited period. The section was too short for an irregularity index to be obtained directly, but an estimate was made from the profiles obtained with the multi-wheel profilometer. The indices obtained were 47 inches per mile for the high side and 65 inches per mile for the low side, although no special care was taken in spreading the concrete, 1½-cubic-yard loads being spread with the hopper

TABLE 6.—THE EFFECT ON THE EVENNESS OF THE FINAL SURFACE AND THE SKIDDING RESISTANCE OF THE METHOD OF FINISHING THE CONCRETE SPREAD BY THE BLADE-TYPE MACHINE

ze f ad ed top rse: bic rds	Profilometer behind second finishing machine			Profilometer in front of second finishing machine with unweighted screed			Profilometer in front of second finishing machine with 500 lb. extra weight in screed			Remarks
	Irregularity index: inches per mile		Sideway force coefficient at 30 miles per hour	Irregularity index: inches per mile		Sideway force coefficient at 30 miles per hour	Irregularity index: inches per mile		Sideway force coefficient at 30 miles per hour	
	High side	Low side		High side	Low side		High side	Low side		
2	95	184*		68	88*		77*	66	0·45	
				87*	96					No information given to vibrator driver
							95*	60		A breakdown occurred in this section
1	86	124*		64	80*	0·60	62	59*		
	71	108*	0·36†							

* Side on which heaps of concrete were dumped
† There was some clay and grit on this surface during the skidding test

machine in the same way as for the slabs which gave irregularity indices of 68 and 108 inches per mile. The result of adding the extra weight was, therefore, to produce a surface as good as or better than could be produced with the most careful spreading. Unfortunately, it was not possible at either site to combine the best spreading technique with the use of the weighted screed but some further improvement in the evenness of the surface might be expected.

The amplitude of the finishing beam.—The irregularity indices of the surfaces produced when the amplitude of the finishing beam was varied are given in Table 5. When machine R, working with the usual amplitude of about 0·02 inch, was used as a finisher behind machine F, the irregularity of the final surface was similar to that when machine R was used alone. The only advantage of this arrangement was the increased speed of construction which could be obtained by using two machines in tandem. Reduction of the amplitude of the finishing machine (machine R) to one-half its usual value did not have much general effect on the regularity, but it did result in a difference in the amount of irregularity between the high and low sides, the size of the bumps appearing to be a little larger on the low side. The further reduction in the amplitude of the finishing machine

to one-quarter its usual value increased the difference between the two sides of the slab and also produced a very uneven surface with most unpleasant waves in it. With this small amplitude for finishing, much less of the initial irregularity was removed and new waves appeared in the surface during the finishing process.

The skidding resistance was also affected by the method of finishing. The sideway force coefficient at 30 miles per hour was completely satisfactory when either machine was used alone. When the amplitude of the finishing machine was reduced, however, the sideway force coefficient decreased, and with the smallest amplitude the surface was only just satisfactory when new. If this surface should polish under traffic it may require some treatment before the road has been used for many years. Reduced amplitudes for finishing, therefore, are not to be recommended.

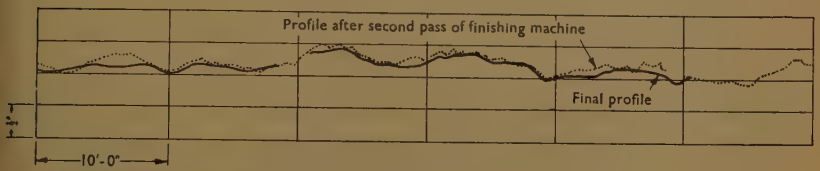
The Effect of the Method of Operating the Finishing Machine

The amount of surcharge.—When the surcharge was reduced to $1\frac{1}{4}$ inch there were some low points and unsealed patches after compaction which were not filled by material brought forward by the screed from the high spots, but which had to be filled by material tamped into the surface. The surface produced in this way when machine F was being used was less regular than that given when the higher surcharge was employed (Table 5), and even when machine R was used little improvement in regularity was obtained. It is necessary therefore to arrange for the level of the spread concrete to be correct at least to within $\frac{1}{4}$ inch if an uneven surface is to be avoided. When power-propelled machines are used the final adjustment of surcharge is made with the oscillating screed of the finishing machine during its first pass; this screed is generally difficult to adjust with the necessary accuracy and cannot easily be returned to exactly the same level when it has once been moved. For smooth operation of the finishing machine the screed should be mounted so that it can be set accurately to within $\frac{1}{16}$ inch. It also seems desirable that the machine should be made sufficiently powerful to remove surplus material over long lengths, since it is extremely difficult to add material to well compacted concrete without adversely affecting the surface.

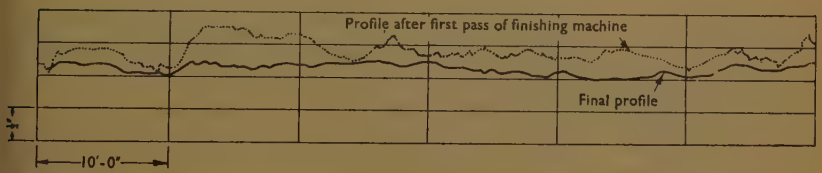
The time at which the surface regularity is checked.—Contrary to expectation, in the first experiment the surface was more regular in the second lane than in the corresponding sections in the first lane (Table 1). Part of the irregularities at the beginning of the work can be attributed to inexperience but this was not considered to account for all the difference since the best section in the first lane was not as good as the worst in the second. During the construction of the first lane the wet-surface profilometer was behind the second finishing machine, so that no correction to the surface could be made before the third pass on the concrete. In the second lane the profilometer was between the two finishing machines and the first pass of the second machine was used to eliminate surface irregularities.

The difference can be seen clearly from the records given in *Figs 17*. These sections were constructed in hot dry weather and when the first measurement of the irregularities was not made until after the second pass of the finishing machine, it was not possible to obtain much improvement in the surface, and the average depth of concrete removed in the finishing process

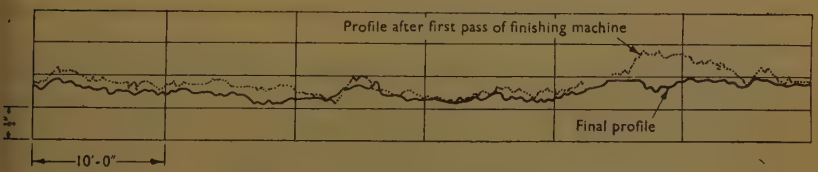
Figs 17



Profiles recorded by wet-surface profilometer behind the second finishing machine



Profiles recorded by wet-surface profilometer between first and second finishing machines



Profiles recorded when the driver of the finishing machine did not have access to the records

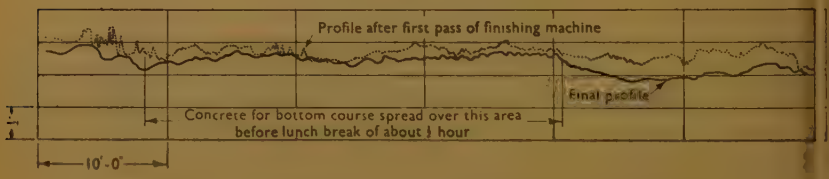
THE EFFECT ON THE PROFILE OF THE TIME AT WHICH THE SURFACE IRREGULARITY WAS CHECKED

was only 0·04 inch throughout this period. When the profilometer preceded the second finishing machine, however, most of the bumps were eliminated, since where there was a high-spot the driver took extra care to try to keep the screed in contact with the forms and where there was a low-spot, the surface of the area was loosened and more concrete added before the second pass. The average depth of concrete removed was increased in this way to 0·09 inch immediately, and to 0·20 inch when experience had been gained in judging the position of the bumps.

The importance of early and accurate assessment of the surface was emphasized by the poor results given when, towards the end of the work, the records of the wet-surface profilometer were deliberately not made available to the finisher driver. The results of the tests with the multi-wheel profilometer are given in Table 6, and typical records taken on the surface of the fresh concrete are shown in *Figs 17*. Despite the experience gained by the driver during the previous tests the lack of any clear indication of the position of irregularities caused the average amount of concrete removed in the finishing process to be reduced from 0·20 to 0·14 inch, and many bumps to be left in the final surface.

The effect of stoppages.—Where work was delayed for some time by a breakdown of the spreading machine the screed of the finishing machine was unable to remove the resulting irregularities even though it was carrying 500 lb. of extra weight (Table 6). For the slabs finished after the

Fig. 18


Profile after first pass of finishing machine
Final profile
Concrete for bottom course spread over this area before lunch break of about ½ hour
10'-0"

THE EFFECT ON THE PROFILE OF A BREAK IN THE CONTINUITY OF THE WORK

breakdown the average depth of concrete removed was reduced to 0·15 inch. This demonstrates the importance of thorough maintenance of the machines to avoid breakdowns.

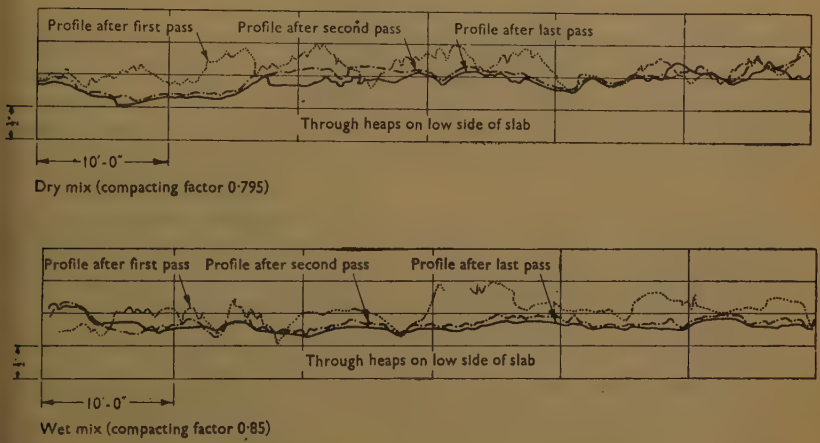
The importance of avoiding any stoppages except at a joint was also shown by the wet-surface profilometer records each day at the lunch break. A typical record is shown in *Fig. 18* where about 30 feet of the bottom course was laid before the break, the top course being spread and the slab finished afterwards. Over this length repeated passes of the finishing machine had little effect, although the surface could be improved relatively easily immediately the machine reached the fresher concrete. There was also some irregularity just before the position of the stoppage ; this has been attributed to the necessity for dumping the first load of concrete partly on the already finished section after the break.

During the construction of both roads, and particularly at the beginning when difficulty was being experienced in the control of the quality of the concrete, fine cracks were noticed in the surface before the concrete had set. A careful survey of the positions of these cracks was made and in twenty-four out of the fifty-one slabs where they occurred the position of the cracks coincided with a break in the work caused by a breakdown of one of the machines. In twenty-three of the remaining twenty-seven slabs there

were long delays owing to difficulty in finishing or to a breakdown in supplies. The incidence of this cracking did not seem to be related to the weather conditions, and it appears likely that these hair cracks running at an angle of about 45 degrees to the edge of the slab are primarily caused by delayed finishing.

The workability of the concrete.—In the first experiment one section, where there was little crossfall, was laid using a wetter mix with the unweighted screed. Although the concrete was dumped from one side of

Figs 19


Profile after first pass
Profile after second pass
Profile after last pass
Through heaps on low side of slab
10'-0"
Dry mix (compacting factor 0·795)
Profile after first pass
Profile after second pass
Profile after last pass
Through heaps on low side of slab
10'-0"
Wet mix (compacting factor 0·85)

THE EFFECT OF USING A MORE WORKABLE MIX ON A SECTION WITH A SMALL CROSSFALL

the lane there was little difference between the irregularity index for the two sides, showing that many bumps attributable to spreading had been removed (Table 7). The improvement was, however, less than had been expected. The wet-surface profilometer records taken after the first, second, and last passes on a typical slab are shown in *Figs 19*, together with those for a slab laid with the original dry mix and the same method of spreading. When the dry mix was used, as has been shown above, the main improvement in the surface took place during the second pass, and there was little improvement thereafter although some fairly large irregularities remained. With the wet mix the second pass of the machine removed most of the large irregularities, and it was expected that subsequent passes could be used to correct those which remained. It was noticeable, however, that there was actually little improvement in the riding quality after the second pass, although the concrete was still workable. It was possible to remove very small irregularities with the subsequent passes, but in one place a new bump was produced: continued working of the wetter mix produced little more improvement

TABLE 7.—THE EFFECT ON THE EVENNESS OF THE FINAL SURFACE AND THE SKIDDING RESISTANCE OF THE WORKABILITY OF THE CONCRETE

Crossfall	Dry mix compacting factor 0·79 to 0·80			Wetter mix compacting factor 0·83 to 0·85			Remarks
	Irregularity index: inches per mile		Sideway force coefficient at 30 miles per hour	Irregularity index: inches per mile		Sideway force coefficient at 30 miles per hour	
	High side	Low side		High side	Low side		
About 1 in 40	68	88*		70*	75	0·47	Blade-type spreading machine with 2-cubic-yard loads in top course followed by machine F with unweighted screed
	64	80*	0·60				Blade-type spreading machine with 1-cubic-yard loads in top course followed by machine F with unweighted screed
	71	108*	0·36†				
	68	108	0·60	65	98	0·64	Hopper-type spreading machine followed by machine F with 500 pounds of extra weight in the screed
	113	92	0·64	83	79	0·70	Hopper-type spreading machine followed by machine R
About 1 in 20	53	65*		58	81*		Blade-type spreading machine followed by machine F with 500 pounds of extra weight in the screed

* Side on which heaps of concrete were dumped
† There was some clay and grit on this surface during the skidding test

in the riding quality than similar extra work on the dry mix. The advantage of the wetter mix was that it enabled a little more concrete to be removed in the first finishing pass, the average depth removed in the line of the heaps being 0·28 inch when the wet mix was used compared with 0·20 inch with the dry mix. These figures suggest that the improvement obtained with the wetter mix was very similar to that achieved with the heavy screed.

The sections laid with a wetter mix in the second experiment confirmed that it did tend to give a slight improvement in riding quality on this level road (see Table 7). The amount of improvement was small, however, when considered in relation to the extra trouble experienced in handling these slightly wetter mixes. The concrete was very sticky and did not discharge freely either from the lorry or from the hopper spreading machine,

so that they had to be emptied partly by hand. If the machines were redesigned so that they would discharge the wetter mix it is probable that the riding quality of the resulting surface would be no better than that achieved with the present machine and the less workable concrete. Some of the cores from these sections are shown in *Figs 20*. There was some honeycombing, when the wetter mix was used, at the bottom of some of them, which may indicate that these mixes are more difficult to compact to the full depth or it may be the results of segregation caused by the poor discharge from the lorries as shown in *Fig. 21* (facing p. 671).

When the workability of the mix was varied where there was a heavy superelevation the drier mix gave the best surface, particularly on the low side where the concrete was dumped, and it is considered that this could only be the result of flow of the wetter concrete. Although the vibrating beam of the finishing machine was set $\frac{1}{4}$ inch below the existing concrete it was difficult to keep the surface clean during the passage of the machines and irregularities actually appeared where they had not been present in the previous pass of the machine.

The skidding resistance of the surface does not seem to have been adversely affected by the use of the more workable mix, but on the contrary it may have been improved slightly. However, the amount of improvement in the riding quality, even on a level stretch of road, was much smaller than that obtained by improvement in the operation of the spreading machine, and the mix was difficult to handle and may have led to some poor compaction. For these reasons it is not likely to be regarded as a satisfactory method of improving the surface finish.

The Alignment of the Formwork

Accuracy of Setting

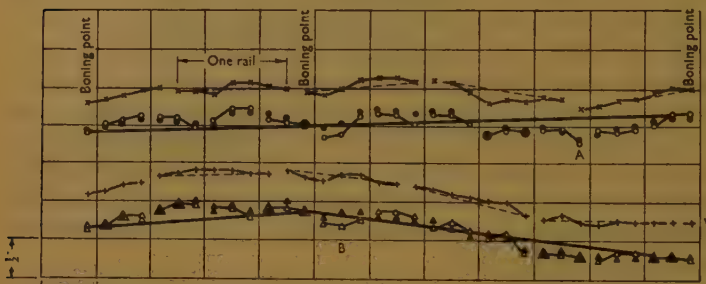
Examination of the accuracy of the tops of new forms showed, that although they were generally true in the centre section, the 1-foot-8-inch-length outside each end stake-housing was often warped. Using the tops of the forms for boning, therefore, could introduce errors of up to $\frac{1}{8}$ inch in the surface, and the stake-housings on which the rails were to be fixed were generally used instead.

The actual levels of the stake-housings both before and after the rails were laid and the levels of the rails were checked during several days' work; a typical length is shown in *Figs 22* (*a*). Although great care was taken in aligning the forms with normal boning rods, errors of as much as $\frac{3}{8}$ inch occurred, although the length of bone never exceeded 100 feet (for example at A). Most difficulty seemed to be experienced in setting the form nearest to the observer, but the maximum did not always occur at this point, and random irregularities of up to $\frac{3}{8}$ inch must be expected. In addition, when the forms were not new, steps of up to $\frac{3}{16}$ inch occurred

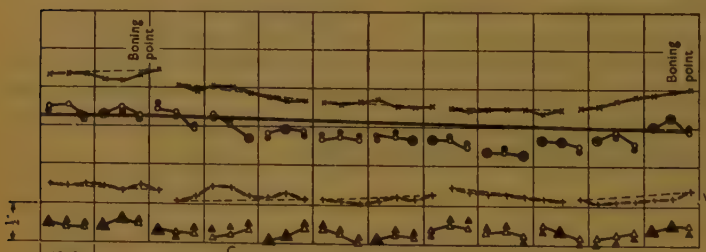
where they were joined together. Some of this irregularity was no doubt caused by the forms becoming warped under constant use so that they were difficult to set, but it was also noticeable that the irregularities increased each time the concreting caught up with the form-laying.

When the rails were fixed they were sufficiently rigid (if the keys attaching them to the forms were driven home) to lift some of the badly set forms

Figs 22



(*a*) LEVELS OF RAILS AND FORMS AFTER NORMAL SETTING



(*b*) LEVELS OF RAILS AND FORMS AFTER SHIMMING

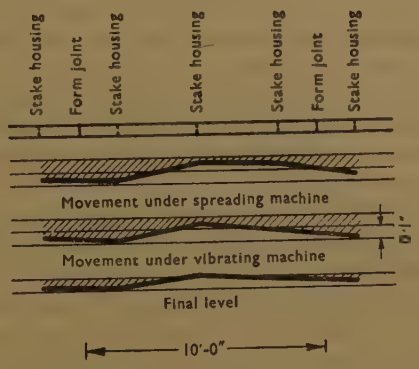
Level of	East side of lane	West side of lane
Forms before rail keys were driven	○	△
Forms after rail keys were driven	●	▲
Rails	×	+

LEVELS OF THE FORMS AND RAILS BEFORE THE PASSAGE OF THE MACHINES

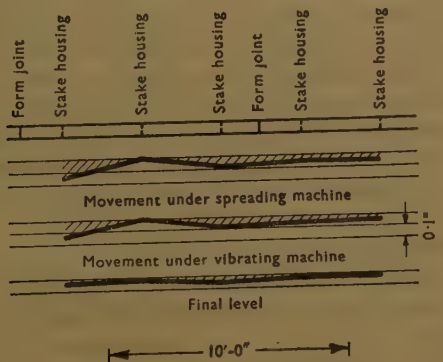
from the sand-cement bed, the form either sliding up the stakes or twisting about the point where it was held by the pegs. Movements of as much as $\frac{3}{16}$ inch were recorded (for example at B) and when a form was raised in this way it was, in practice, unsupported. If the keys were not driven home the rail was not in contact with every stake-housing and it was again unsupported for a length of more than the 3 feet 4 inches for which it was designed. In practice it was often unsupported for a length of more than

10 feet, and permanent deflexions occurred during the passage of the spreading and finishing machines. A record of the movements occurring under the machines was obtained with the special gauges, and is given for a typical section in *Figs 23* (*a*). Deflexions of as much as $\frac{3}{16}$ inch

Figs 23



(*a*) LEVELS OF RAILS AFTER NORMAL SETTING



(*b*) LEVELS OF RAILS AFTER SHIMMING

THE MOVEMENTS OF THE RAILS UNDER MACHINES

occurred at stake-housings under both the spreading and the vibrating machines, and after the slab had been finished there was a permanent deflexion of $\frac{1}{16}$ inch at one point.

The amount of deflexion was obviously related to the closeness of contact between the rail and form, and between the form and the sand-cement base. When a set of new rails was obtained, therefore, a stretched fishing line,

50 feet long, was used to select shims $\frac{1}{16}$ inch, $\frac{1}{8}$ inch, or $\frac{3}{16}$ inch thick for each 24-foot rail length so that the straight rail would be supported by each housing. The line was reset for each rail but the 50-foot length enabled each rail to be set in relation to the end of the previous one and the general level of the one to follow. The levels of the stake-housings were checked before and after the rails had been fixed and are shown in *Figs 22* (*b*). With the exception of one point C, where a badly bent rail was used, the levels of the rails were very uniform and there was little if any movement of the forms when the keys attaching the rails were driven. The movements occurring under the machines are shown for a typical length in *Figs 23* (*b*). There was much less deflexion than with normal setting and little permanent set. Levelling the rails with a stretched line did, therefore, give better alignment, less movement under the machines and less permanent bending of the rails.

From diagrams similar to *Figs 22* the differences were measured between the actual levels of the rails and their intended levels, and the profiles of the surface caused by the inaccuracies of the formwork were calculated for the lines of the profilometer recording-wheels by proportion. From these profiles the record, which would have been given by the multi-wheel profilometer on this theoretical surface, was estimated so that an approximate value of the irregularity index given by the unevenness of the forms could be obtained. When the rails were set in the usual way the value was about 21 inches per mile but when they were specially levelled it was reduced to about 9 inches per mile. No allowance was made in this estimate for movements of the rails under the machines which might be expected to increase the value for the normal setting, but it is clear that the use of a stretched line or wire to ensure that the rails are properly supported should lead to an improvement. This was confirmed by a comparison of lengths otherwise laid in a similar way in which the careful levelling of the forms reduced the final irregularity from 94 to 82 inches per mile.

Settlement During Construction

In the work already described the forms were laid on a thin sand-cement bed on the old concrete road and there could be little settlement under the machines, but at Site 1 the sand-cement bed was laid on the prepared formation. Levels taken before and after the passage of the machines showed that in these circumstances subsidence generally occurred, and that this could amount to as much as 0·8 inch. In the same way as the accuracy of setting, the amount of subsidence increased when concreting caught up with form-laying, since the time interval for the sand-cement mix to harden was shortened. These results emphasize the importance of organizing the work so that the form setting is always well ahead of concreting.

In the same way as before, an estimate has been made of the irregularity index given by the profile of the forms. With the amount of settlement

occurring here it could be as much as 25 to 30 inches per mile, whilst if allowance is made for permanent sets in the rails and forms, this figure might be increased to 35 inches per mile. Although the total irregularity of the road would not be reduced by the whole of this amount if the forms were perfectly aligned, considerable improvement in riding quality could be obtained if the method of setting the formwork was improved.

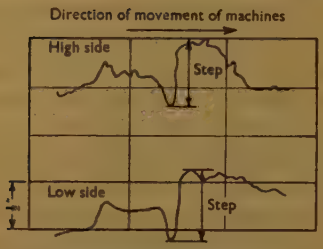
The special gauges for recording form movements under the machines were used to measure the deflexions of the rails and were also placed at rail joints occurring over a form joint, between stake-housings not at a form joint, and over a stake-housing. Deflexions of the rail of up to $\frac{3}{16}$ inch occurred at the centre of the span even where there was no joint. The rails which were 3 inches deep were expected to carry the load of the machines without much deflexion and most of the movement was probably the result of the incomplete support by the forms which has previously been referred to. Where the rail joint coincided with the stake-housing the amount of deflexion was similar but when it was between stake-housings there was sometimes a much greater deflexion, which, although the bolts in the fish-plates were carefully tightened, amounted in one case to as much as $\frac{3}{8}$ inch. With this amount of movement, duplicate hollows of as much as $\frac{1}{4}$ inch could be produced in the surface.

These large deflexions did not occur at all such joints, and the movement was also probably affected by the amount of support given to the rail in the vicinity. The movement under the vibrating machine was sometimes noticeably greater than that under the spreading machine although in most cases they gave a similar amount of movement. This was probably owing to the vibration shaking loose the keys attaching the rails to the forms and the pegs attaching the forms to the stakes, so that the rail was free to rise behind the machine, thus permitting an increased deflexion. The keys and pegs were often loose after the slab had been finished and it seems desirable that more positive methods of fixing should be developed. The movements at the rail joints can be overcome by placing hardwood supports under each joint, but for future work arrangements should be made for all rail joints to occur at stake-housings, and for there to be some special fixing at these points.

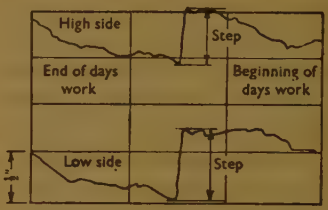
The Effect of the Joints

Variation in the amount of hand finishing makes it difficult to assess, from the profiles of the finished surface, the relative effect on the riding quality of the road of different types of joint. Examination of the records obtained by the wet-surface profilometer suggested that an assessment of the amount of irregularity likely to be produced could be obtained more easily from the record after the first pass of the vibrating machine and before any finishing took place. After this first pass each type of joint gave a characteristic bump, as shown in *Figs 24*, and the magnitude of the step

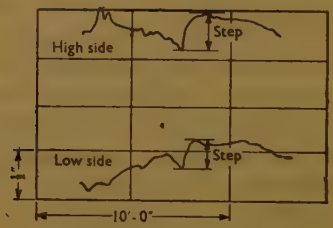
Figs 24



EXPANSION JOINT IN THE MIDDLE OF A DAY'S WORK



EXPANSION JOINT AT THE END OF A DAY'S WORK (STOP END)



DUMMY JOINT

THE IRREGULARITIES PRODUCED BY DIFFERENT TYPES OF JOINT

was measured for each joint. The average steps for each of the three types of joint employed at Site 2 and for the expansion joints at Site 1 are given in Table 8.

TABLE 8.—THE IRREGULARITIES PRODUCED BY DIFFERENT TYPES OF JOINT

Type of joint	Irregularity of joint after first pass of vibrating machine		
	Number of joints measured	Average amount of bump : inch	Standard deviation
Expansion joints during the day's work at Site 1	178	0·19	0·11
Expansion joints during the day's work at Site 2	178	0·33	0·18
Expansion joints at the end of a day's work at Site 2 (stop-ends)	124	0·44	0·24
Dummy joints at Site 2	352	0·23	0·14

At Site 2 the greatest irregularity occurred at stop-ends (significant at the 1-per-cent level) and the least at dummy joints, the expansion joints giving an intermediate amount. The shape of the irregularities was

similar and can be attributed to the interruption of the vibrations by the solid material interposed in order to make the joint. Experiments [6] have shown that with the machines used, the vibrations are transmitted at least 2 feet in front of, and 2 feet behind, the beam, so that the concrete is partly compacted before the beam reaches it and the surface partly finished after it has passed. The concrete behind the joint was thus left high since it was not so compacted as that in the middle of a slab before the beam passed over it, and the concrete in front of the joint did not rise so much as usual behind the vibrating beam, since the vibration was cut off quickly. The size of the irregularity can thus be attributed to the amount of resistance to the transmission of vibrations which was offered by each type of joint; the stop-end would naturally prevent any transmission, the expansion joint would permit a little through the ½-inch layer of concrete over the filling material, whilst the dummy joint would permit the transmission of all vibration which penetrated below the rubber-covered bar.

The expansion joints formed by the same method previously were significantly more regular and the size of the step was as small as that given by the dummy joints at Site 2 (Table 8). It seems probable that this was caused by the small difference in the construction procedure. The 2-foot-wide strips of concrete on each side of the joint at Site 1 were partly compacted before the main mass of the concrete was spread, and the depth of the concrete to be vibrated near the joint was thus much less than the full depth of the slab, so that the reduction in vibration caused by the resistance of the jointing material was of less importance. This suggests that the unevenness at joints may be reduced by compacting some concrete on each side of the filling material before the main mass of concrete is spread, or by running the compacting machine much more slowly over the joints than in the centre of the slab.

Conclusions

Spreading

The evenness of the finished surface depends upon the evenness of spreading and, when an attempt was made to limit the irregularity of the final surface, it was found that the number of finishing passes required was reduced by more even spreading. Existing spreading machines do not automatically give concrete of uniform density and it is important to control the method of operation carefully.

Reciprocating-blade machine.—The least irregularity was obtained when heaps of about 1 cubic yard of concrete were dumped from both sides of the slab at regular intervals (irregularity indices of 63 and 77 inches per mile). When the concrete was dumped only from one side the irregularity on this side was considerably greater than on the other, and it was necessary to tilt the strike-off screed in order to obtain uniform compaction. When heaps were dumped too close together there was some honeycombing at the bottom of the slab.

Hopper machine.—The most even surface was obtained when, for both top and bottom courses, a second pass with a fully-loaded hopper was made over the surface of the concrete which had already been spread (irregularity indices of 50 and 79 inches per mile). The disadvantages of this method were that it caused some delay, and that concrete was pushed over the forms making it difficult to keep the rails clean.

Finishing

The machine.—The removal of irregularities was no easier when using the machine with the rigidly-supported beam and screed than when using the machine in which they were freely supported. Measurements of the mean position of both vibrating beams showed that the concrete was depressed under the beam as it passed over a bump and rose again behind it. The vibrating beam cannot be used, therefore, to correct irregularities and these must be removed by the oscillating screed. The freely-supported screed had a tendency to ride over some of the bumps so that they were not removed during the finishing pass; increasing its weight reduced this tendency, so that even with poor spreading the irregularity index in the line of the heaps of dumped concrete was reduced to 77 inches per mile. There was no rise or fall of the rigidly-mounted screed, but its shape and relative nearness to the vibrating beam enabled the concrete to be depressed under it and rise behind it in a similar way to that under the vibrating beam.

Small amplitudes for finishing are not to be recommended. When the amplitude was reduced for finishing to less than that used for compacting there was some reduction in skidding resistance and when the reduction in amplitude was considerable it gave rise to an unpleasant wavy surface.

The method of operation.—It is easier to produce an even surface if the correction of irregularity is effected entirely by the removal of surplus material than if it is necessary to import concrete to fill any hollows. The removal of irregularities becomes increasingly difficult with each pass of the finishing machine, and little improvement in the surface can be obtained after the second pass. Every stoppage of work leads to an uneven surface and sometimes to fine surface cracks as well.

The workability of the concrete.—When the spreading was poor the riding quality of a level stretch of road was improved by substituting a mix of "low" for one of "very low" workability. The wetter mix, however, was difficult to handle and also appeared to lead to some honeycombing at the bottom of the slab, and when there was a heavy superelevation the flow of the wetter concrete resulted in an increase in irregularity on the low side.

Formwork

Even with high-quality workmanship and good supervision, the forms were sometimes as much as $\frac{3}{8}$ inch out of alignment when set by boning in

the usual way, and were considered to be responsible for an irregularity index of as much as 20 inches per mile. Settlement under the machines on some subgrades may increase this amount to between 25 and 30 inches per mile.

The errors in alignment resulted in the rails on which the machines were run not always being supported at the intended interval, and deflexions of up to $\frac{3}{16}$ inch occurred during the passage of the machines. These deflexions were halved, and the irregularity index caused by uneven formwork was reduced to about 10 inches per mile when the rails were aligned with a stretched line and packed before being keyed to the forms. When rail joints did not occur over stake-housings there was sometimes an excessive deflexion caused by lack of support resulting from the uneven setting of the forms. The deflexions appeared to be increased by pegs and keys working loose as a result of the vibration.

Joints

Each joint gave a characteristic bump after the first pass of the compacting machine, the amount of the step being greatest at stop-ends and least at dummy joints, expansion joints in the middle of a day's work being intermediate. The size of the irregularity can be attributed to the amount of resistance to the transmission of vibrations offered by each type of joint. Some improvement might be obtained by running the compacting machine more slowly over the joints or by compacting some concrete on each side of the joint before the main mass is spread.

Recommendations

Examination of these results has led to the conclusion that new types of machinery are required. In the United States of America recently, a machine has been developed which combines the operation of spreading and finishing and which does not require formwork [7]; similar developments are desirable in Great Britain. At the same time the following recommendations for improvements in existing methods should be considered :—

(1) New types of spreading machines are required which will lay the concrete to a uniform density without the necessity for rigid control of the method of operation in order to ensure that concrete roads will have good riding qualities.

(2) The design of the oscillating screeds of finishing machines should be improved so that they can be set more accurately and so that they remove irregularities more easily. An autographic irregularity recorder fitted to the finishing machine would be of great assistance in helping the operator to improve the riding quality.

(3) The work should be organized to reduce stoppages to the minimum.

(4) There should be some improvement in the method of aligning and fixing formwork.

Finally it is possible to conclude that with improved spreading and finishing techniques and accurately aligned forms and rails there is no reason why concrete surfaces should not be laid with as true a riding quality as the best roads in the country. Careful spreading will also lead to economy in construction.

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The Paper is accompanied by nine photographs and seventeen sheets of tracings, from which the half-tone page plates and the Figures in the text have been prepared.

Discussion

The Author, in presenting the Paper, said that the most important of the factors examined seemed to be the method of spreading the concrete. With spreading machines of the blade or screw type it was necessary to dump

the concrete on the formation, and the tests had shown that the evenness of the finished surface was related to the size of the dumps. The maximum size of the heap which could be tolerated was, of course, related to the methods of deposition and finishing. Loads of 1 cubic yard seemed to be satisfactory when they were tipped from lorries, provided they were not tipped too quickly, but that size of load tipped from a Paver mixer might lead to trouble.

Since the Paper had been prepared, an opportunity had been taken to examine the finished surface where heaps of 37 cubic feet were being dumped from each of two Paver mixers. When no particular care was taken, the heaps had sometimes overlapped and bumps of as much as ½ inch were left at those points in the finished surface. Those bumps had occurred on the average about once every 50 feet and could be regarded as being responsible for about 40 inches per mile of the total irregularity, which was between 110 and 140 inches per mile. Later, more care had been taken in placing each load and the bucket of the Paver had been used to distribute the concrete instead of dumping it in heaps. In that way, a much more even surface had been produced, the irregularity index being reduced to between 60 and 70 inches per mile. The importance of properly spreading every batch, therefore, could not be over-emphasized.

Mr Alan P. Lambert said that during the 6 years he had served on the Committee which dealt with concrete-machinery for road work, he had developed a profound respect for the meticulous care with which the Author had prepared his reports, and in the present Paper there could be seen the same painstaking manner in which he had carried out the full-scale research work described.

Reading between the lines, it was evident that the Author had had quite a lot of difficulties to contend with. He had had machines that broke down, labour that was totally inexperienced ; he had had to control concrete which was mixed 2 miles away in small mixers, and so forth—all of which must have added considerably to the difficulty of obtaining scientific data from the work.

The Author had hoped to try a worm spreading machine, but had not been able to obtain one. It might be of interest to mention an experience on the Hatfield runway with such a machine. Mr Lambert's firm had been constructing a runway with a very dry zero-slump concrete, using a screw spreader and a paddle spreader ; it had been found that the screw spreader was definitely less satisfactory than the paddle spreader. It had all the disadvantages, of course, of dealing with concrete shot on to the formation, but in addition the concrete which it moved across the bay became fluffed up by the worm and was even less dense than the concrete which was moved across to the other side of the bay by the paddle in the other sort of machine. Furthermore, the shearing action of the paddle as it swept the top of the heap away did not seem to produce any transverse reaction on the form-work, but when the worm was fully engaged in a heap of very dry concrete,

there was a definite transverse reaction causing the machine to try and wind itself off the forms. He therefore thought there was no future for a worm spreader of the present type when dealing with zero-slump concrete. It had been designed in America for a much wetter concrete, and the particular disabilities of the machine might not apply to the wet concrete.

Of course, the most important point brought out by the Paper was the way in which the irregularities in the density of the spread concrete affected the final road surface. At the moment, contractors appeared to have the worst of two worlds: first, they had spreading machines which those researches had shown were not capable under normal operation of producing concrete of uniform density; and secondly, compacting machines, all of which had been designed on the tacit assumption that the concrete they would be asked to compact was of uniform density. Probably the solution would lie in some entirely new spreading machine, such as the American one referred to at the end of the Paper; but Mr Lambert would like to put forward an interim proposal which might go some way towards overcoming the difficulty of pre-compaction caused by discharge from lorries on the subgrade.

He suggested that if the concrete were to be run from a mixer in a mobile agitator, there would be a considerable improvement. First, those machines would preserve the quality of the mix much better than would transport in an open lorry, and secondly, they could discharge their concrete in a controlled manner on to the formation practically without shock, and distribute it over a fairly large area of the formation, possibly not across the full width of the bay unless the machine was allowed on to the formation, but certainly over a much larger area than was the case when shooting the concrete out of a lorry. Furthermore, the concrete delivered by the mobile agitator would not be subject to the segregation which occurred, particularly when two lorry heaps intersected.

That method of distributing concrete would allow the continued use of the paddle spreader which, from the commercial point of view, was more attractive than the trough spreaders, although (as the Paper showed) it was less satisfactory on technical grounds. The attraction of the paddle spreader was that it was a fast-working machine and was not tied intimately to the supply of concrete. The lorries or mobile agitators could tip independently on to the formation, whereas with a trough machine (he had not used one, but he imagined it to be the cause) the trough must be available to receive each lorry load, and if the trough had to wait at any time or the lorry had to wait for the trough, time was irretrievably lost.

Whilst, of course, it was essential to produce concrete roads of excellent quality, it was also essential that they should be produced in a manner which was economical to the community, and therefore it was important to develop machines and techniques which were economic in addition to being technically good.

In that connexion, he did not think that the various devices—such as

using half lorry-loads or travelling the trough fully loaded over concrete already spread—which the Author had adopted to improve the quality of spread concrete, could be regarded as a proper solution on commercial grounds, and he did not suppose that the Author put them forward as a solution ; they merely emphasized and underlined the fundamental problem which was still awaiting solution.

Concerning the performance of compacting machines, Mr Lambert thought that on the whole they had come very well out of the test, bearing in mind that they had been designed on the assumption that concrete of uniform density would be offered to them. *Figs 13* seemed to indicate that the best result was the last one on the second line, and the next best result was the second one on the lower line ; both of those results had been achieved by a single pass of the vibrating machine. It was reasonable to claim therefore that, given the right concrete, a good finish could be produced in one pass.

In the experiments covered by the Paper, those compacting machines had not succeeded in removing very satisfactorily the irregularities left after the first pass of the machine ; but he thought that in fairness to the machines it should be pointed out that they had never really been intended to do that. He thought that the oscillating screed in front of the machine was there for the express purpose of striking off the uncompacted concrete to a precise surcharge, and was never intended to scrape, say $\frac{3}{8}$ inch off a small area of a compacted surface. If compacting machines, no matter what one might achieve in the way of spreading, were still to be capable of removing those small surface irregularities, then they required some special mechanism which was not yet available ; it might take the form of a horizontal shaft in front of the machine, possibly with helical blades, in such a way that those blades would definitely cut the high parts of the concrete. The Author had referred to the question of tearing the surface. Mr Lambert would have thought that if attempts were to be made to remove $\frac{3}{8}$ inch from compacted concrete made with aggregate up to $1\frac{1}{2}$ inches, then the fact would have to be accepted that the surface would be torn. He would have thought that the vibrating beam following along very quickly behind would have restored the surface, but from what the Author had said it sounded as though it did not work out quite like that.

The expedient of letting the oscillating screeds try to remove the high spots was justifiable in view of the experimental nature of the work, but Mr Lambert did not think it could be regarded as an economic solution to the problem without considerable modification to the design of the screeds.

Form fixing was a very important matter, as the Paper had clearly shown, particularly when working on a natural subgrade as opposed to working on an existing concrete slab. He thought that the best way of bringing about an improvement in form fixing would be to treat that operation in specifications and bills of quantities as a more important work, and when the nature of the subgrade made it necessary to provide either a

shallow concrete or a cement-sand foundation, then that foundation should be measured and paid for; otherwise, there was the danger that the employing authority would hope that the contractor would pay for the foundations, and the contractor would hope that it might not be necessary to provide them; in those circumstances the final result would not be satisfactory.

Whilst the Paper dealt primarily with the spreading and compacting of concrete between main expansion joints, the data given on p. 677 showed that joints were still potentially the biggest source of individual irregularities in the finished surface, and Mr Lambert felt that the perfect joint had not yet been found. He believed that there were machines, possibly still in the experimental stage, which would endeavour to cut the joints after the stab had been placed, and if that could be done successfully, he thought it would be a great step forward in the general running surface of machine-laid concrete roads.

He wished briefly to refer to the information given about cores on pp. 670 and 671. In general, cores were taken for a variety of reasons, but in the case under discussion they had been taken to examine the compaction of the concrete, and the point arose as to whether in that context they should be graded according to their appearance or their strength. The odd-numbered cores in Table 2, with the exception of the first one, showed better compaction than the even-numbered cores, and yet were graded below them because their strengths were slightly lower. There were, of course, many things which affected the strength as well as the compaction, and althought those cores had been checked to some extent by cubes taken from the same slab, he thought it would be almost impossible to say that the cubes had been taken from the same mix as the cores.

Mr Lambert was a little puzzled about some of the imformation given in Tables 2 and 3. It would appear from Table 2 that cores Nos 2 and 10 were batting for the concrete that was spread by the machine; in Table 3, however, cores Nos 2 and 10 appeared to have been taken from the line of dumps, in contrast to cores Nos 12 and 11 which were cores taken from the spread concrete. He might have misunderstood that, but if there had been a slip and if cores 2 and 10 should be on the right-hand side of Table 3 and cores 11 and 12 on the left-hand side, then the ratios, which were an important part of that Table, would not be correct; in fact, the reciprocal of the ratios would be correct, and the point which the Author was making from that Table, although possibly true, would not be supported by the core evidence.

In conclusion, he agreed with all the Author's recommendations, although they might be difficult to bring about. Could the Author give a little more information about the American machine which appeared to be such a big advance on present methods in Great Britain?

Mr R. R. W. Grigson said that since half the work which was described in the Paper had been done in his county (Leicestershire), he wished

to mention some of the difficulties which had been encountered and some of the lessons which had been learned from the work.

First, with regard to manpower, like most highway authorities in the Midlands, and possibly elsewhere, Leicestershire was short of manpower, and the result had been that, although he had wanted to do the work by direct labour, he had not had the resources to tackle it entirely, so that it had been necessary to make use of a batching plant belonging to a firm which specialized in ready-mixed concrete. That firm had produced batches gauged in accordance with the specification—four batches in a lorry. The batches had been brought to the job, tipped into the hopper of a travelling mixer and discharged from the travelling mixer by means of a boom and bucket into the spreader box. That had meant that the weigh-batching of the material had not been under his immediate control. There had been concurrent demands on the firm for ready-mixed concrete, and since ready-mixed concrete was a more profitable line than plain batched concrete, he had got the rough end of the stick. There had been some other big jobs going on in the vicinity where there was a large demand for ready-mixed concrete, with the result that the stockpiles had been eaten up and the material had not been standing sufficiently long to ensure an absolutely uniform moisture content. There had been violent fluctuations in the moisture content in the aggregates reaching the job, and that had resulted in considerable difficulties.

Another difficulty had been that a proportion of the aggregates were oversize. They had been put through a crushing machine and then reintroduced into the screens and the stockpiles. That had meant a varying amount of crushed aggregate in the material which was being used, and that had of course had an effect on the workability of the concrete.

There was another lesson which he had learned and which, although it appeared to be an obvious thing, had been overlooked by him entirely. The near lane had been constructed first. Judging from the amount of wear that was occurring on the road, that lane carried 80 or 90 per cent of the traffic. In starting and learning the job, the workmanship had not been anything like as good as later when working on the second lane (the overtaking lane). The moral, of course, was that one should construct the overtaking lane first and learn the technique before starting on the lane which really carried the traffic. A very much better road would have been provided for the majority of people if the offside lane had been done first.

On p. 685 the Author had referred to the fine cracks in the surfaces where the concrete had been left and then worked. It had alarmed Mr Grigson to see those hair-cracks running across the slab at an angle of 45 degrees. There had been a very large number of them, but very soon after completion of the job, they had disappeared completely ; at the time they had been very alarming.

In connexion with irregularities, the Paper emphasized the importance of forms. Mr Grigson had been rather disconcerted to find that the majority

of the forms obtained for the job—which were absolutely new forms of heavy construction—were not straight. It seemed to him to be a rather unsatisfactory state of affairs that reputable firms could not produce straight forms. Many of them had been $\frac{1}{8}$ inch, or even more, out of alignment before being used.

The Author had also referred to the question of meal breaks. Breaks of any description in that sort of work showed up at once; but how one could overcome that difficulty, he had no idea. It would be extremely difficult to breed a race of British workmen who would work right through the day without stopping for three-quarters of an hour or so at mid-day. The alternative was to have a relief gang come on while the first gang had their lunch, and economic considerations would not allow that. It was very difficult when everybody downed tools on a really hot day and walked off; one knew that the concrete was getting stiffer and setting, and there was nothing one could do about it. The meal break business was a real problem.

On the question of joints, in the description of the site on p. 668 the Author had referred to the fact that the start there had been 150-foot-long bays with dummy joints at 25-foot intervals; but after talking that over with the Road Research Laboratory, it had been decided that it would be best to drop dummy joints altogether and risk the odd crack, because with the dummy joints it had not seemed possible to get smooth joints, so that after two-thirds of the first lane had been constructed the rest of the job—that was to say, the whole of the overtaking lane and the remaining one-third of the nearside lane—had been completed without dummy joints, and expansion joints had been put at every 100 feet. So far as could be seen, there had been very few, if any, cracks as a result of dropping the dummy joints. Mr Grigson did not think they were really worth having.

In spite of the many experiments that were being tried, the road construction work had progressed very smoothly. The Road Research Laboratory had organized their work in such an excellent way to fit in with the normal routine that they had not introduced any appreciable delays. He wished also to pay a tribute to those making the experiments for the assistance they had given.

He wished in conclusion to endorse the Author's concluding remark that "with improved spreading and finishing techniques and accurately aligned forms and rails there is no reason why concrete surfaces should not be laid with as true a riding quality as the best roads in the country." The surface at Six Hills was, like the curate's egg, good in parts; but the parts that were good, were very good indeed. Now that there were parts which were superlatively good, Mr Grigson thought that it was only a question of time before it would be possible to lay all concrete roads as well as the best sections on Six Hills, as a result of the research which the Road Research Laboratory had carried out.

Mr J. M. Fisher said that the main point established by the results

presented in the Paper was that at present the evenness of the surface of machine-laid concrete roads was inferior to the best which could be produced in a bituminous surfacing, but there was not a great deal to choose between them when the concrete was laid under the most favourable conditions.

He was very pleased to note that the Author, in his recommendations, placed first and foremost the need for new spreading devices which would lay the concrete to a uniform density without any necessity for special attention being paid by supervisory staff to that point. There was, in Mr Fisher's opinion, no other single factor which contributed so much to the lack of planeness of a surface or uniformity of compaction and hence strength in the slab itself, than poor or indifferent spreading. A prerequisite of uniform spreading was, of course, that the workability of the concrete itself must be as uniform as possible, and to that end accurate proportioning of properly graded materials was essential. The attainment of a uniform workability found by experiment to be that most suited to the finishing machines was preferable to the maintaining of a fixed water/cement ratio in the concrete.

The quality and accuracy of the formwork were clearly of great importance in the construction of a road surface. No amount of attention to accuracy of spreading or uniformity of concrete could produce a profile which was better than that of the forms, but as the Paper showed, it could be a good deal worse.

The Author had referred in his introductory remarks to a test carried out since the main experimental work reported in the Paper had been completed. The results were, in fact, spectacular, ranging from a very indifferent profile where the concrete was dumped in an erratic manner to a good profile ranking with the best that was recorded for the experimental work in South Wales and Leicestershire, when the paver operator spread the concrete as uniformly as possible. Quite apart from the improved profile attributable to the change in the mode of spreading, the surface was finished to an even profile very much more expeditiously where the concrete had been spread correctly. If improvements of that magnitude could be brought about by a simple change in the method of operating a machine such as a paver, how much better results would be attained if a process whereby the effects of variable pre-compaction were eliminated could be devised. The problem should occupy the minds of all whose aim was to improve the quality of concrete roads.

The Author had also recommended that improvements in the design of finishing machines be made, particularly in respect of oscillating screeds. Whilst Mr Fisher agreed with the Author that refinements were desirable in respect of some machines which were currently in use, he was of the opinion that their performance would leave little to be desired had the concrete on which they were used the desired uniformity.

While discussing finishing machines, he wished to refer briefly to the fact

that some present-day versions were equipped with rotating paddles for trimming the surface prior to finishing, in place of the oscillating screeds fitted to the machines described in the Paper. Would the Author consider that method of planing to be superior to the use of an oscillating screed ?

One of the chief difficulties with vibratory finishing machines was that concrete which they were vibrating always tended to flow to the low side of the bay. Where crossfalls were variable both in sense and degree, as would be the case in a road for high-speed traffic curvilinear in plan, that tendency would call for constant alteration of the settings of both oscillating strike-off screeds and vibrating beam. It was conceivable that some automatic device which would make the necessary adjustments according to the crossfall could be devised, but there again uniformity of the concrete in front of the machine was presupposed.

An alternative which might be satisfactory would be to mount between the vibrating beam and the back finishing screed a form of transverse paddle such as was to be found on a subgrade planer. That could operate in either direction and transfer concrete which had migrated from the high side to the low side of the bay back to its proper position.

Although the Paper dealt mainly with the riding quality of concrete roads, it should not be overlooked that uniformity of strength was just as necessary a feature of a good road as an accurate surface profile. Whilst there was little doubt that proper compaction could be attained if the desiderata of uniformly suitable concrete and accurate spreading were attained, the extremely favourable results which were noted in some recent examples of rolled lean-mix concrete led one to wonder whether the vibratory methods of compaction used in present-day finishing machines were in fact the best ones to use. It might well be that the development of a finishing machine on the general pattern of the vibrating rollers, which were being increasingly used at the present time, would lead more readily to the ultimate goal to complete compaction and uniform surface profile than the methods with which they were concerned at present.

The joints in a concrete road gave rise to more adverse comment on their riding quality than any other factor, and he understood that about 20 per cent of the total irregularity might be associated with about 10 per cent of the slab lengths in the immediate vicinity of joints. In other words, the quality of the surface around the joints left much more to be desired than it did elsewhere. The making of a good joint in a concrete road seemed to have been always a besetting difficulty, but methods of reducing the irregularity associated with them were being developed and used with some success. One of those was the cutting of the compacted concrete with a vibrating blade. That method had the advantage that the concrete could be compacted in the normal way straight through the joints, and since no obstructions of any kind were encountered the profile in the line of the joint was as uniform as elsewhere. The vibrating knife, however, necessarily displaced some concrete if it was fully compacted, but the amount

was comparatively small and could generally be dispersed over a reasonable width on either side of the joint by hand finishing. One major drawback of that method was that as at present developed it could not be used when the joint was dowelled.

It was an unfortunate feature of concrete road and runway construction at the present time that the amount of labour required to finish off the concrete after the passage of the machines might be almost as great as that required to produce and lay the concrete. One could only look forward to the day when the labour behind the machine was reduced to the bare minimum required for the occasional touching up which was almost inevitable in any similar process.

Mr B. F. J. Bradbeer believed that the Author would remember some of the earlier remarks which he (Mr Bradbeer) had made concerning the opinions formed on trials of concrete finishing and compacting machines, so long ago as 1938 and 1939. The result had been that the machines had been sent away and consideration given to the various problems that had been encountered. Most of the features mentioned in the Paper had been apparent at that time, such as the irregular pre-compaction caused by the dumping of concrete, further pre-compaction by trampling on the concrete where hand spreading was employed, the uneven condition of the concrete caused by segregation where concrete was hauled some distance after being mixed, the difficulty of laying concrete with a uniform surcharge, and finally, the inadequacy of design and lack of rigidity of the road forms in common use.

Those views, stated when he had met the Author for the first time, had been only opinions, and it was therefore a great pleasure now to read the Paper and see how the Author, by his research, had in certain cases given something more than opinions—namely, the proof and the answer to many of the problems, or at any rate the reasons for them, leaving engineers to consider what could be done by way of providing answers

It was quite obvious to all that spreading was one of the biggest problems yet to be solved and that, without an answer to that problem, the finishing and compacting machines were being asked to do far more than they were designed to do. The mere fact that finishing machines were called upon to pass two, three, and four times over a surface was sufficient condemnation of the methods of the mixing, tipping, and spreading of concrete in the first place. Some who had had the opportunity of seeing the German *autobahnen* works and similar works would know that it was possible for machines to travel and to finish concrete in one operation and not need to go back at all. When that stage was reached, he thought that many of the other problems with which they were troubled would disappear.

The Chairman said that the problem of securing an even distribution was an old one.

He had been hoping that some comments would have been made on the Barber-Greene, because although that machine, as made for tarmacadam,

was not strong enough for concrete, it seemed to him that it was a principle which could be applied satisfactorily to concrete. Apparently the Author thought there were difficulties about the wear and tear of the machine.

Mr D. A. Stewart said that the unevenness of density had been traced back as far as the spreader, but it seemed to him that the unevenness of the concrete, so far as segregation existed, went right back to the mixer. He had very strong feelings on that subject because in the application of vibration to jobs other than roads he had often had a great deal of trouble as a result of mixers which in point of fact did more to segregate than they did to mix.

Behind the mixer there was, again, the trouble of aggregates. He thought that every engineer and every contractor realized that they were very much at the mercy of the suppliers of aggregate. Although the suppliers had themselves produced a specification, which he believed was No. 882, very few of them seemed to realize its existence and none that he knew of really made an effort to keep within its wide boundaries.

If that was the case and if uncontrolled aggregates were passed into a mixer, which separated the sand from the coarser material and stuck it on the side of the drum and if, eventually, the concrete was dumped into a spreader or on to a formation where it got partially compacted, it did not give a real chance to the vibrating equipment which was to make the road; nor did it give the wretched passenger who was riding in the car afterwards a feeling of smoothness—which perhaps he deserved after paying vast sums for that surface.

Mr J. M. Fisher, referring to the Chairman's comment on the use of the Barber-Greene finisher for bituminous work and his query as to whether such machines had been used for laying concrete, said that his firm had recently been concerned with laying a lean-concrete base for a concrete slab on an aerodrome; practically the whole of that concrete, which was 4 inches thick, had been laid by means of a Barber-Greene machine.

He understood that one of the reasons for using the machine was that it had not been possible to obtain correct depth in the short time available. The Barber-Greene machine had therefore been used, and the results appeared to be extremely satisfactory.

The concrete had been laid by the machine and then compacted by means of an 8-ton tandem roller, and the output of concrete per 8-hour day had been governed not by the capacity of the machine to lay the concrete but by the capacity of the mixtures to produce the concrete. The machine had been standing for a considerable percentage of its time because the mixing capacity had not been sufficient to cater for the total machine capacity.

The Author, in reply, agreed that many of the conclusions reached appeared to be self-evident. The difficulty had been, however, that although all engineers knew that a great deal was wrong in the handling of fresh concrete, they had, in the past, lacked the measurements which

indicated what proportion of the total irregularity was caused by each operation. In the Paper, an attempt was made to give a picture of the relationship between the different operations.

He had been interested to hear that the variation in the density of the spread concrete was even greater when using the worm spreading machine than when using a blade machine. In view of that fact, and the practical difficulties encountered by Mr Lambert when using a machine of the screw type, there seemed to be no need to carry out tests on one. The proposal that the concrete should be transported to the site in an agitator, so that it could be distributed over a wide area of the formation, indicated a possible solution and should be tried. However, there might be difficulties in the use of either agitators or truck mixers, since those machines would not easily handle concrete of the quality which was best for modern compacting machines. That concrete, which had to be of very low workability, was difficult to discharge without loss of fines which were left sticking in the mixer drum, and in one of the tests reported in the Paper, the mix proportions had had to be altered to allow for that loss of fines. That difficulty was particularly marked with truck mixers or agitators and, if they were used, there might be an increased variation in the workability of the concrete, which would lead to as much difficulty as the presence of heaps on the formation. The effect on riding quality of random variations in workability had not been examined in the tests described in the Paper, because the lengths available had not been sufficient for that factor to be included. At times, however, as Mr Grigson had pointed out, there were considerable fluctuations in the concrete workability and the results obtained indicated that the amount of pre-compaction given to the concrete might well have depended as much on its workability as on the method of spreading. Further tests to examine that point were desirable.

The devices adopted during the tests for improving the uniformity of the spread concrete were not submitted as a final solution but, although they were only expedients, it was not certain that they would prove uneconomical. The Author had been glad to hear from Mr Fisher that the improved spreading with the Paver mixer not only gave improved riding quality, but also resulted in economy. Observation of the work in Glamorgan and Leicestershire had suggested that if the primary difficulty of spreading could have been overcome, it would have been possible not only for the roads to have had better riding quality, but also for construction to have proceeded more quickly with much less supervision, which would have resulted in real economy.

As Mr Lambert had suggested, the vibrating beam could be used during the finishing pass to try to restore the surface which had been torn when the oscillating screed had been used to remove high spots. Unfortunately, most of the material scraped off during the removal of those bumps was mortar, and it was not easy to re-seal the surface when the bumps had been as high as $\frac{3}{8}$ inch; consequently, a mix of very low workability had been

used. Under those circumstances, it was often necessary to make several finishing passes and to try to add mortar to the torn surface.

The Belgian machine with the rotating paddles in place of the oscillating screed was more likely to cut the surface to an even profile than either of the machines which had been tested. The paddles were rigidly mounted and since they were mounted well forward of the vibrating beam it was unlikely that the concrete would flow under them. In Belgium, however, although a dry mix was used for road work, it was much richer (1 : 4½) than that used in Great Britain, and any loss of mortar in removing irregularities would be less noticeable. If the machine was used on a dry lean mix it was likely that there would be more tearing of the surface than if a machine of the more usual type was used, and consequently there would be more difficulty in finishing—which might itself lead to irregularity. It would be interesting to carry out tests on that machine, but it was probably more important to improve the technique of spreading, since finishing machines had not really been designed to remove irregularities of up to ⅜ inch, such as had been shown to exist.

The compaction of lean dry concrete bases by rolling was becoming a common form of construction, but it was not certain that that was a step forward. The roller might have good compaction of thin layers, but it had yet to be proved satisfactory for slabs 8 or 9 inches thick and it seemed unlikely that its use would lead to improved riding quality. At the point where the roller was reversed there were always irregularities which could not be removed.

In some of the United States, cutting joints in the hardened concrete was preferred to forming them during construction. With hard aggregates such as those generally used in the United Kingdom, however, the method appeared likely to be costly. In the few cases where it had been tried, the cost had been three or four times that of the usual method of forming joints, and for that reason it was not a satisfactory solution to the problem. Cutting the concrete with a vibrating knife immediately after it had been compacted appeared to be more promising, but it was possible that the bump inevitably produced by the displaced material might be as objectionable as those given by the joints described in the Paper. It was desirable that tests of that machine should be made, in which records of the profiles were taken before and after the joints were cut. At present he agreed with Mr Grigson that there was an increased irregularity at joints, and was glad to hear that the expedient of cutting out a lot of the dummy joints had not resulted in many extra cracks. At the time, the Author had been dubious about that particular part of the experiment.

The cores referred to in Table 2 had been taken either from where the edges of two heaps overlapped or indiscriminately from the other parts of the slab ; the lower caption in the column headed " Core number " should read " (*b*) Cores taken from the centres of heaps or from the concrete spread by the machine." That arrangement had been considered desirable in

view of the differences between cores taken from the centres of heaps or from the spread concrete as shown in Table 3. He thought that the cores should be graded according to their strength and not their appearance, since it was very difficult to look at a core and judge the percentage of voids. One or two large voids were immediately noticeable but a large number of minute voids, which would have an equally important effect on the strength, could easily be neglected. He would rather grade cores on the basis of their strength in relation to the strength of the same concrete when fully compacted, and on that basis there was a significant difference owing to the segregation caused by the handling of the concrete.

For the Barber-Greene machine to be used for concrete it would need to be modified to avoid excessive wear of the bar feeder and to lay a greater thickness of material. The American machine for laying concrete, to which reference had been made, was intended primarily for the construction of low-cost country roads. It was similar to the Barber-Greene machine and ran on crawler tracks. The concrete was tipped into a hopper in front of the machine which spread it, and at the back there was a vibrating beam to compact it. A short length of formwork was attached to the machine and moved along with it, the mix used being sufficiently stiff to remain without slump as the forms travelled forward. At present, however, the machine was not intended to give improved riding quality and did not incorporate any device similar to that in the Barber-Greene machine by which the surface being produced was related more closely to the surface just finished, than to the undulations in the track or subgrade. The development, however, was encouraging, since it showed that a single laying machine was possible for unreinforced concrete as well as for bituminous work. If the method of spreading and finishing in such a machine was designed carefully, in order to give an even surface, it would be possible to achieve both economy and improved quality. It would, however, need considerable alteration before it could be used for laying trunk roads in which reinforcement and dowelled joints were required.

He wished to thank both the County Surveyors concerned and their staffs and the other members of the Road Research Laboratory who had assisted in carrying out the work. Only the forbearance of the County Surveyors and their staff had made it possible to alter the procedure from day to day without any guarantee that the alteration would, in fact, result in the improvement expected. He had been glad to hear Mr Grigson say that the road was good in parts. He could only wish that the experiments had been of such a nature to ensure good riding quality for the whole length.

The closing date for Correspondence on the foregoing Paper has now passed without the receipt of any communication.—Sec. I.C.E.

RAILWAY ENGINEERING DIVISION MEETING

(in conjunction with the Works Construction Division)

16 April, 1953

Mr J. C. L. Train, Member, Chairman of the Division, in the Chair

"The Reconstruction of French Railways"

by

René Miot

The following is a summary of the introductory remarks with which Mr Miot prefaced the display of a film upon the above subject.

The French railways first suffered during the battle of France in 1940, when the bridges over many main rivers were demolished. This damage, however, was repaired by 1942. The worst period was in 1944, when the Allied bombardment, the sabotage by Resistance forces, and strategic destruction by the retreating enemy together put the greater part of the railways out of action. Destruction included 120 main passenger stations, 25 marshalling yards, more than 3,000 bridges, about 1,870 miles of main-line track, and 1,120 miles of service lines. By August 1944, the French railway system was reduced to a series of disconnected sections, each about 6 miles long. The railways were then urgently needed to supply the advancing Allied armies and the country itself.

Immediate reconstruction necessitated rejoining the sections and establishing direct routes. Owing to the scarcity of materials, ingenuity had to be exercised in making use of recoverable girderwork, rails, etc.

By September 1944, Paris was again connected with all the main cities in France, but the country was virtually divided by the River Loire, and extensive detours were necessary when travelling to the south.

Restoration of direct lines, however, was almost achieved by the end of 1945, by which time 1,430 miles of track had been re-laid.

Efforts have been made, throughout the programme, to profit by modern technical methods and equipment. The opportunity was taken, for example, to electrify the Paris-Lyon and Valenciennes–Longuyon lines. The permanent reconstruction works are now nearing completion.

On the motion of Mr A. S. Quartermaine, Member, seconded by Mr D. M. Watson, Member, the thanks of the two Divisions were accorded to Mr Miot.

ROAD ENGINEERING DIVISION MEETING

28 April, 1953

Brigadier A. C. Hughes, Member, Chairman of the Division, in the Chair

The following Paper was presented for discussion and, on the motion of the Chairman, the thanks of the Division were accorded to the Author.

Road Paper No. 42

"The Design of Motorways" *

by

Thomas Edward Hutton, B.Sc., A.M.I.C.E.

SYNOPSIS

The location and design of new motorways has been proceeding for a number of years, and the Paper discusses the basic principles which seem appropriate in the light of this experience.

Preliminary reconnaissance and the more detailed study of alignment are first considered, and this is followed by an analysis of the lay-out of a motorway and the reasons for adopting certain standards.

For purposes of design it is necessary to determine the capacity of carriageways constructed to the standards required for a motorway and the average speed of vehicles as well as the most suitable design speed is considered. These factors have a bearing on such things as the minimum radius of curvature, visibility distances, superelevation, and transition curves.

In addition to meeting the technical demands of a high-speed road it is important that the new roads should merge into the landscape and be pleasing to look at. Some of the features which assist this purpose are mentioned.

On the subject of junctions it is emphasized that standard designs cannot be rubber-stamped on to the drawings, and careful consideration of the topography and traffic conditions at each site is necessary to produce a lay-out wholly suitable to the individual problems and requirements.

There is a brief reference to bridges and the plans required for the approval of a Scheme under the Special Roads Act, 1949, and also the contract drawings for a later stage.

Introduction

The Special Roads Act, 1949, gives the powers necessary for a highway authority to construct roads for special purposes, and one of these purposes is to provide roads for the exclusive use of motor vehicles. There was no statutory authority to construct such roads prior to the passing of this Act, and although it has not yet been possible to embark upon the construction of new motorways, a great deal of preparatory work has been carried out and is still going on.

The object of this Paper is to set down the basic principles of design

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which now seem to be appropriate, and to give some indication of the great scope for individuality in the creation of these engineering projects, which, to a large extent, will form the backbone of future development.

Proposed System of Motorways

The ultimate system of motorways at present envisaged by the Ministry of Transport is shown in *Fig. 1*. This differs to some extent from the scheme published by the Minister in May 1946, and further amendments may be necessary as investigations proceed. The total mileage is about 800, and nearly all the preliminary reconnaissance has been completed with the greater proportion surveyed in detail.

Preliminary Considerations

Motorways may incorporate part of an existing road under Section 1 of the Special Roads Act, but more often they will be entirely new roads. They are expensive to construct and generally occupy land for which there are competing claims from agriculture and other developers. It is essential, therefore, at the outset to consider carefully the full justification for the new road, and to ensure that it is located where it will give maximum benefits to traffic and minimum interference with agriculture.

The Ministry of Transport census figures give valuable information about the volume and character of traffic using existing roads in the vicinity, but a carefully planned origin-and-destination survey may be required.

The bulk of traffic moves between centres of population and the volume of through-traffic, not wishing to call in the larger towns, is often surprisingly small. For this reason the tendency to plan by-passes well clear of built-up areas has been modified and although this increases the difficulties of location there is usually a saving on the construction or widening of the road linking the motorway with the town centre.

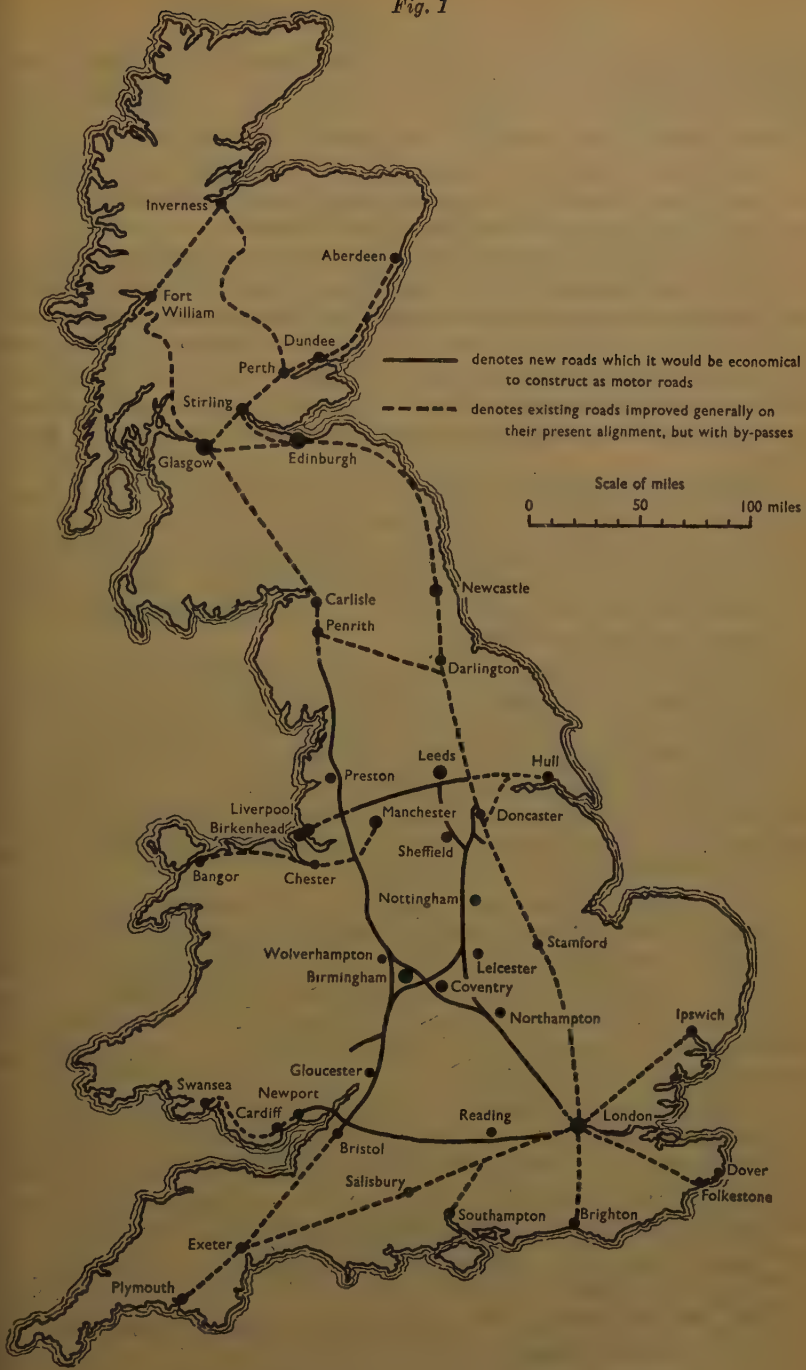
The ideal solution for traffic would be to carry the road into the town as an elevated (or sunken) highway, and although there are several striking examples of this form of construction in the United States of America, it is hardly necessary to point out the enormous cost and interference with valuable property entailed in such projects. It is a method which must be considered in important cases, however, if only as a long term scheme.

Detailed Consideration of Alignment

Having decided that a motorway from A to B is justified and the general route it should follow to obtain maximum benefit to traffic movement, the next step is to consider location in greater detail.

The location engineer will already have some knowledge of the ground, and before instruments are taken out a great deal of useful preliminary work can be done by consideration of the 6-inch and 2½-inch Ordnance

Fig. 1



THE FUTURE PATTERN OF PRINCIPAL NATIONAL ROUTES

maps. The latter have contours at 25-foot intervals and although these are only interpolated they are very useful, and it is a simple matter to transfer them to $\frac{1}{2500}$ maps if work on this more familiar scale is preferred.

It is a good plan to plot a rough line with the aid of these contours, and in difficult country where gradients and heavy earthwork may be a problem a longitudinal section should also be drawn.

Possessed of this information, a walking reconnaissance will show whether or not the suggested line is sufficiently clear of valuable property, and if reasonable gradients can be obtained without heavy earthworks. Attention must be given to road junctions and bridge sites to ensure that they are convenient and economical, and the manner in which the road will merge into the landscape should be visualized. Additional contours may be sketched in at this stage either by eye or with the aid of a hand-level.

The question of flowing alignment can be considered in more detail later, and it is a waste of time at this stage to try to obtain an exact balance of cut and fill. Some consideration must be given to the earthwork problem, however, and in particular the possibility that a proposed bridge may interrupt the haulage of earth and so make it desirable to achieve a balance on each side of the bridge.

It is advisable to prepare a map of farm boundaries and the 6-inch scale is suitable for this purpose. The required information can usually be obtained from the local office of the Ministry of Agriculture and Fisheries without approaching individual farmers, and useful advice on the quality of the land can be obtained at the same time. Some obvious adjustments to avoid severance of the best agricultural land will become apparent and these should be incorporated wherever possible without relaxing the minimum standards of design.

Before detailed surveys are commenced, or at least before they reach an advanced stage, it is necessary to consult a number of authorities in addition to the Ministry of Agriculture who may be interested in the use of the land. The Act provides that any person or body affected by the proposals will have an opportunity at a later stage of objecting to the scheme, and it is obviously good practice to learn of any such objections and meet them so far as possible.

If highway authorities are not responsible for the survey, early contact should be made with them and also with any local planning authorities affected. Other interests which may be affected on a large scheme are given below, and the Divisional Road Engineers of the Ministry of Transport will assist in contacting the appropriate authorities :—

(1) National parks (National Parks and Access to the Countryside Act, 1949).

(2) Ancient monuments and buildings of special architectural or historic interest.

(3) Forestry, Section 28 of the Town and Country Planning Act enables local planning authorities to make orders providing for the preservation of trees and woodlands in their areas and the Forestry Commission may control certain areas for re-afforestation or other purposes.
(4) Navigation.
(5) River conservancy. Catchment and Drainage Boards.
(6) Airfields and other Service establishments.
(7) Public undertakings. Consultation with the Railway Executive and the Docks and Inland Waterways Executive is necessary where bridges or other works affecting these undertakings are involved.
(8) Mineral workings.

Surveys

The plan begins to take shape when this preliminary reconnaissance is completed, and survey work is then required in order to fix the line in greater detail and to make such further adjustments as are necessary. Ground surveys are the normal method in this well developed country but aerial surveys are sometimes more expeditious where a long length of new road is to be considered.

It is worth noting that powers of entry to land for the purpose of making the survey, including soil survey, are given by Section 11 of the Special Roads Act, which also refers to certain supplementary provisions in the Town and Country Planning Act, 1947. The location engineer must be duly authorized in writing by a highway authority, and admission must not be demanded to enter any land which is occupied unless 24 hours' notice of the intended entry has been given to the occupier. Provision is made for the recovery of compensation for any damage which may be done in making the survey.

In practice it is seldom necessary to use these powers since farmers and land owners are usually willing to co-operate, provided the engineers for their part do no damage and comply with reasonable requirements. It is obviously desirable to time any survey work through wooded country so that it can be carried out before the trees are in full leaf, and a time-table is also useful in order to avoid damage to growing crops.

An elementary point, which is nevertheless worth mentioning because it is such a frequent source of trouble, is that survey pegs should be removed or driven well down if there is any risk of damage to agricultural machinery.

There are various ways of doing the actual survey, but at this stage there are advantages in tacheometrical work carried out with sufficient spot levels to produce 5-foot contours on the $\frac{1}{2500}$ Ordnance maps, as described in a Paper by J. E. Cardell and H. Howarth.[1] This method is

[1] The references are given on p. 736.

quick on the ground and has the advantage of avoiding too much speculation about a preliminary line which may not be the one finally adopted. It also allows considerable variations of the line to be examined without any further field survey. The contours give a good guide when fixing the line, and it is a simple matter to produce longitudinal sections for any number of promising possibilities because, whatever natural aptitude the engineer may possess for road location, there is no substitute for solid hard work on the ground and in the drawing office. In undulating or hilly country there may be several possibilities to fit the many requirements of a good economical line and all should be examined with care.

When the contours have been plotted on $\frac{1}{2500}$ Ordnance sheets it is advisable to have them photographed. Any number of prints can then be obtained and used to try out variations of the line without destroying the original.

Longitudinal sections are drawn to the same horizontal scale of $\frac{1}{2500}$ but with a vertical exaggeration of 10 to 1. Standard profile paper (or tracing linen) can be obtained, and since this is already ruled in suitable horizontal and vertical lines the process of plotting is very quick. Vertical curves are usually drawn on the exaggerated profile with circular railway curves and this is sufficiently accurate at this stage although exact curve calculations will be necessary later, particularly at bridge sites where headroom is critical. An example of plan and profile is given in Figs 2, Plate 1.

There are certain key dimensions which must be observed when plotting the profile. For instance, a clear headroom of 16 feet 6 inches must be provided when any road or railway is taken over the motorway, and the same clearance is required for most roads taken under the motorway. The only exceptions will be underbridges for minor roads and farm accesses, and possibly a road which already has a bridge of lower headroom which is never likely to be adjusted and where there is an alternative route.

At this early stage, before the bridges have been designed, it is convenient to allow a height of 20 feet between the road surfaces of the two roads, but this will have to be adjusted later in the interests of accuracy and economy.

For railways the desirable standard clearance above rail level is 15 feet [2] but the clearance of existing bridges over the railway may be somewhat less and it is best in all cases to consult the Railway Executive.

The statutory clearance for high-tension electricity cables carrying a voltage not exceeding 66,000 volts is 20 feet, but this clearance is required when the cable is running at a temperature of 122° F. The additional sag of the conductors between normal temperatures and 122° F. is appreciable and if there is any doubt or the new road is planned to pass under the lowest point of the cable it is advisable to consult the Electricity Authorities. The height of cables can be increased but it is costly and worth avoiding if possible.

Finding the right plan and profile is largely a matter of trial and error and a good deal of revision may be required as new factors come to light in the detailed development of the scheme. When at last the right line seems to have been obtained on the drawings it is advisable, in difficult country at any rate, to set out the line accurately on the ground with all transitions. A really accurate ground profile can then be plotted and cross-sections taken at suitable intervals. This extra work may seem unnecessary till a later stage but it will almost certainly lead to further refinements and since many stretches of motor road may cost around £200,000 per mile it is well worth while. Setting out has the further advantage that land owners can understand a line of pegs or ranging rods far better than a plan and on several occasions it has been possible to meet some objection by a minor variation. Even if the line cannot be altered it provides an opportunity to explain why and this may forestall a formal objection at a later stage.

Soil Survey [3, 4, 5]

A preliminary soil survey is usually required on a large scheme although much useful information can be obtained from the solid and drift maps with their associated Survey Memoirs prepared by the Geological Survey. The availability of such information, the nature of the country and the size of the proposed works will determine the extent of the soil survey and subsequent soil testing. It may vary from the simple case requiring only shallow hand-auger borings and identification tests to a survey necessitating deep borings, rock drilling, and considerable testing.

Unless there is reason to believe that existing soil conditions will be a major factor, it is better to fix the line with a reasonable degree of accuracy before starting the soil survey. The results may show that some minor adjustments of horizontal alignments are desirable to avoid bad ground, but it is more likely that the main benefits of the soil survey will come from adjustments to the profile.

A preliminary soil survey is usually sufficient to assist in fixing the best line and it will reveal those areas where more detailed information is required when contract details are being prepared. This preliminary investigation is usually confined to borings at deep cuttings or where there is to be a high embankment or some major engineering feature such as a large retaining wall or bridge. The information thus obtained is essential for foundation design and tests will also be carried out to determine the suitability of material intended for filling and to reveal sites for borrow-pits.

In addition to trial borings it is possible to amplify the information so obtained about the depth to bed rock by a geophysical survey. This is specialist work if sufficient accuracy is to be obtained but it is quick and relatively cheap.

In preparing a bill of quantities for the soil survey it should be

remembered that hand augering is not satisfactory in soil containing many large stones. For depths up to 5 feet in this material, or even deeper if the subsoil water is not a serious handicap, it is better to dig a trial pit. Similarly, percussion boring with continual breaking out is difficult where boulders are large and frequent and, if the object is to determine the depth to bedrock it has been found cheaper and quicker to set up a rock drill and go through both boulders and clay until a sufficient penetration is achieved. In gravelly soil, a mobile power-auger capable of drilling holes up to 4 feet diameter is suitable to a depth of about 20 feet.

Sampling and Testing

Undisturbed core samples are taken in cohesive soils whenever there is a major change in the type of soil and small hand-samples consisting of auger parings are taken at intervals of about 2 feet 6 inches between the core samples.

It is a simple matter to take disturbed samples, but undisturbed samples require the most careful handling and are expensive. They should only be taken therefore when required for specific tests. The numbers and types of test will be related to the purpose of the survey and to the engineering problems at any particular place. It is unnecessary to carry out a complete range of tests on every sample since it will be possible to classify most of them by visual inspection or by simple identification tests. Representative samples of the various types of soil encountered should be tested in more detail, however, and for this purpose sieve analysis, and more occasionally full mechanical analysis, shear tests, compaction tests, and California Bearing Ratio determinations will probably be the most important. Tests on the suitability of soil for cement stabilization for use in base construction may be required and consolidation tests are useful for the design of important structures.

A great deal of valuable information on soil surveys has been published in recent years and some of these publications are mentioned at the end of the Paper.

Fitting the Road to the Landscape and Flowing Alignment

These two factors work in opposition to some extent and for this reason they are coupled together here. In broken country, a road closely following the ground line will undulate and twist in a disconcerting manner and this approach to " fitting the road to the landscape " is clearly going to extremes quite apart from the engineering problem of providing suitable curves and gradients. On the other hand, a perfectly flowing alignment may introduce excessive cuts and high embankments, so once again the engineer must use his talent for finding the proper balance.

Much attention has been given to these problems in recent years, and we can profit from the experience gained by the construction of the German motor-roads. Fortunately, men such as Koester and Lorenz found time

during the Second World War to set down some of the principles which had become apparent as the result of practical experience, and these have been interpreted and developed in the Paper by Cardell and Howarth, already referred to, and in a Paper by W. H. Spencer.[6]

A few of the more important points which help to produce harmony of line are given below :—

(1) If a vertical curve is not entirely on a straight section of road, efforts should be made to extend it from the commencement to the end of a corresponding horizontal curve. This is not always possible without excessive earthworks and in such cases a little latitude is permissible, but the aim should be to obtain a reasonable balance of the two curves.

(2) A combination of short curves and straights should be avoided. Horizontal and vertical curves should be as long as possible and adjacent curves should be of comparable length.

(3) Perspective views of the road ahead need either background or continuity, and therefore the road should not form part of the horizon.

(4) Long straights are permissible on level ground but tend to be monotonous ; it is therefore an advantage if they can be sited to give a view ahead of some prominent feature which need not necessarily be situated centrally.

(5) Curves in the same direction connected by a straight do not look well, and should be avoided unless they are hidden from each other by a fold in the ground.

(6) Abrupt development of superelevation will introduce a visual "kink" unless the rate at which it is applied does not exceed one per cent over the general gradient.

(7) The treatment of the slopes of cuttings and embankments is an important factor in merging a new road into the landscape, and this will be considered in more detail later.

Lay-out

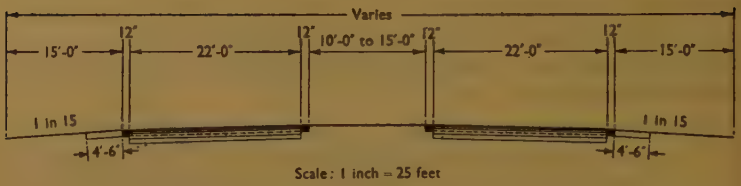
A typical cross-section for a motorway is shown in *Fig. 3*, and it will be noted that dual 22-foot carriageways (plus marginal strips each 1 foot wide) are separated by a 10-foot to 15-foot central reservation with verges each 15 feet wide in an overall width of 88 feet to 93 feet.

This is not a hard-and-fast lay-out, and although it is considered that it will prove satisfactory for many miles of the proposed motorways, local variations will be required, and the factors which influence these will be considered.

Number and Width of Carriageways.

Dual carriageways are regarded as essential on a high-speed motorway although it is possible that considerations of economy may sometimes

Fig. 3



TYPICAL CROSS-SECTION OF MOTORWAY

dictate that one carriageway only shall be constructed in the first place. The ultimate plan should always provide for dual carriageways, however, so that opposing streams of traffic are well segregated in the interests of safety.

The volume of traffic to be expected on the new road will determine the number of traffic lanes required on each carriageway. In this connexion perhaps the most valuable features of a motorway are :

(1) the absence of standing vehicles,
(2) the elimination of frequent cross roads, and
(3) the design of junctions so that through traffic is not impeded.

These desirable improvements greatly increase the capacity of each lane and a vehicle of comparatively modest top speed will still maintain a good average.

Owing to the greater spacing of vehicles as speed increases, the capacity of a road in numbers of vehicles per hour only increases up to the surprisingly low speed of about 20 miles per hour when the capacity of one traffic lane is around 1,800 vehicles per hour.

American authorities [7] quote a maximum of 2,000 vehicles per hour, provided the following five conditions are satisfied :—

(1) There are at least two lanes for the exclusive use of traffic travelling in one direction.
(2) All vehicles move at approximately the same speed, each driver being restricted to the speed of the vehicle ahead. This speed, which is governed by the speed of the slowest drivers, must be between 30 and 40 miles per hour.
(3) There are practically no commercial vehicles.
(4) The width of traffic lanes and shoulders and clearances to vertical obstructions beyond the edge of traffic lanes are adequate.
(5) There are no restrictive sight distances, grades, improperly superelevated curves, intersections, or interferences by pedestrians.

A properly designed motorway will take care of conditions 1, 4, and 5, but there is likely to be a considerable number of commercial vehicles and many of them will move at speeds less than 30 miles per hour. Few drivers are content to move at the speed of the vehicle ahead, and if the road is not to be unduly congested and if a reasonable safe average speed is to be maintained, it is clear that the practical capacity of a traffic lane is much less than the possible maximum.

Bearing this in mind it is considered that the reasonable capacity for a uni-directional unobstructed carriageway may be taken safely at 1,000 vehicles per hour per traffic lane.

It is interesting to note that at holiday times, short bursts of traffic approaching 2,000 vehicles per hour per traffic lane have been counted on some of the main roads on the outskirts of London, and the Outer Drive in Chicago with eight lanes of traffic has accommodated an average of 1,958 vehicles per hour per lane in one direction of travel during several periods when manual counts were taken.

Ministry of Transport Memorandum No. 653 [8] states that plans should be based on an estimated future volume of traffic 75 per cent in excess of the average daily figures obtained in 1938, but special considerations such as the development of new towns and location of new industries may justify an increase in this figure.

It is unlikely that more than dual two-lane carriageways will be required in this country for many years, except for a few comparatively short and exceptional lengths.

Kerbs and Marginal Strips

In general, kerbs are not required on motorways except at bridges and their approaches but a marginal strip 1 foot wide in a colour which contrasts with that of the carriageway, especially at night time, should be provided on each side of the carriageways. The inner edges of the strip should be flush with the carriageway, and the outer edges flush with either the hard shoulders or the central reservation.

Central Reservation and Verges

The desirable width for both central reservation and side verges is 15 feet but this is by no means a fixed dimension since it may have to be decreased in the interests of economy in the use of land or, in other circumstances, it may be increased.

It may be advantageous on steep sidelong ground for instance to construct the carriageways at different levels and in such a case the width of the central reservation is governed only by engineering considerations and the problem of land severance.

On the other hand, in the case of long high embankments or long deep cuttings a considerable saving can be effected by a reduction in width. The absolute minimum for the central reservation in order to allow for

overhang is 4 feet (6 feet if there are to be lamp standards) but such a narrow width should not be adopted for a motorway except in the most unusual circumstances. In general, the minimum width should be not less than 10 feet and before deciding on this there are one or two factors which must not be overlooked. For instance, if a future widening of the carriageway is contemplated the additional width might be provided in the central reservation. On a bend it may be necessary to superelevate each carriageway separately and this could give an excessive back-fall across the central reservation if it is not sufficiently wide. This might be taken up by a low wall, but the possible need for a drain in the central reservation must also be kept in mind.

The width of side verges is governed by considerations of amenity, the need for drainage, adequate clearance for signposts and visibility on bends. They may be reduced to 5 feet at overbridges and an upstanding guard-kerb must be provided in these cases. Underbridges will generally be constructed to the full width for spans up to about 30 feet and the side verges will be reduced to 5 feet for spans over 30 feet. A cross-fall of 1 in 15 is recommended for side verges.

It is clearly undesirable to reduce the width of the central reservation locally, and when required over a long length it is best accomplished on a curve where the narrowing can be arranged without reverse curves and without being unsightly.

It is often necessary to use the central reservation for the provision of a light-well in the case of underbridges of short span and comparatively long length.

Hard Shoulders

The value of hard shoulders on the side verges adjacent to the carriageways has been increasingly recognized in recent years. They encourage drivers to keep to the near side without fear of hitting a kerb or striking a soft patch and also enable them to turn off the carriageway for an emergency stop.

A width of 4 feet 6 inches is suitable and the hard shoulders should be continuous on each side verge, but not on the central reservation.

The method of construction is given in Clause 808 of the Ministry of Transport Specification for Road and Bridge Works.[8]

Lay-bys

The function of lay-bys is to provide facilities for vehicles to draw out of the main stream of traffic for adjustments and repair, for drivers to take meals or the statutory rest period prescribed in Section 19 (2) (a) of the Road Traffic Act, 1930. Another important function of particular value on a motor road is to allow the travelling public to enjoy a good view from the highway without impeding the flow of traffic. Where this latter reason does not fix the siting of a lay-by it is a good plan to provide for breakdowns by siting them at or near the lowest points of gradients.

It is suggested that lay-bys should be provided by stages according to need and they may be required eventually on both carriageways at intervals of about a mile.

The width should normally be 10 feet and in no case less than 8 feet. The length will be determined by the volume and character of traffic on the road but will normally be about 100 feet, excluding provision for entrance and exit.

Trees and Shrubs

Trees and shrubs must be planted with discrimination, and too much regularity or planting in rows should be avoided. Narrow margins leave little scope but irregularities in the fence line will often give an opportunity to plant in groups. Large-scale planting of trees or shrubs is seldom necessary and the primary objective should be to preserve existing features and so keep a natural foreground in harmony with the distant view.

New trees or shrubs may be used to hide unsightly or distracting objects and, on the other hand, there will be many unpleasant growths which can be cut down to expose a better view.

Trees must be selected with particular regard to their environment, habit, safety, and general suitability for planting in a public road. Any which are liable to become dangerous because of falling branches or which shed large leaves in the autumn should be avoided and so also should those with roots liable to cause shrinkage of a clay subgrade. On the other hand, the technical advantages of planting trees and shrubs can be quite considerable. They may be useful for supporting the soil of cuttings and, in suitable positions in the central reservation, will help to screen the headlights of approaching vehicles.

Soil 18 inches below the surface is almost completely deficient in the organisms necessary for the growth of plant life and good top-spit soil must be imported if necessary. All top soil should be preserved carefully by dumping it on one side when excavation starts.

Hedges and Fencing

Hedges should harmonize with the surroundings and form part of the road planting scheme. Some counties have a preference for walling or banks surmounted by a hedge and, while due regard must be paid to local custom, the question of cost and the avoidance of a shut-in effect must be considered also. Lengths of hedging or fencing should be reasonably consistent along the road.

Maintenance is a problem, and a hedge which requires cutting more than once a year to preserve a good appearance should be avoided.

Hawthorn is excellent for retaining live stock and if too much of it is considered monotonous, it can be relieved by interspersing plants such as maple and dogwood, which give good autumn tints. Beech, although not so strong as hawthorn is also suitable, especially on chalk or limestone.

and the coppery colour of the leaves in winter is always attractive. On heavy soils, hornbeam is preferable but it is rather slow growing. Each forms a close hedge without cutting down when young and does not need clipping more than once a year, but the alternative shrubs mentioned above cannot be layered as successfully as hawthorn.

A protective temporary fence will generally be needed during the early years of growth, but in the case of motorways it should be sufficient to have one on the field side.

The temporary fences in general use are :—

(1) Post and rail, which is perhaps the best, particularly if the hedge is likely to be slow in maturing.

(2) Cleft chestnut, which is not so permanent as post and rail but satisfactory if the hedge develops quickly.

(3) Post and wire. This fence is not always acceptable to farmers but it is cheap and more readily obtainable.

Permanent fences of different kinds are detailed in B.S. No. 1722–1951, Parts 1 to 9.

Design

Weight of Traffic

It is sometimes necessary to move heavy indivisible loads having weights in the region of 200 tons, but such loads are always carried on special vehicles with many wheels to spread the load and they travel very slowly. Having regard to the weights of vehicles at present permitted by regulations, and making allowance for possible future increases, it is considered reasonable to design the foundations and carriageways of motorways to withstand a wheel load of 15,000 lb. This load includes for impact effects and occasional more severe stresses caused by heavy indivisible loads.

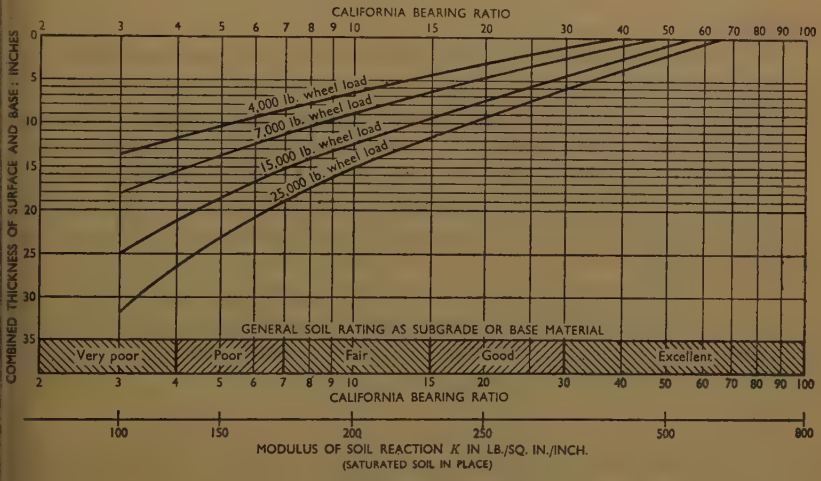
The weight of traffic is carried ultimately by the subgrade and the California State Highway Department found that the minimum thickness of the road crust could be related with reasonable accuracy to the California bearing ratio of the subgrade. This is now a well recognized method of pavement design and *Fig. 4* shows the minimum thickness of flexible construction required in relation to the C.B.R. The thicknesses give reasonable immunity from frost damage but an increased thickness may be advisable for special cases. The method is not strictly applicable to the design of non-flexible pavements but as a guide the required thickness of reinforced and un-reinforced concrete may be taken as one-half and two-thirds respectively of the thickness of flexible pavement shown in Table 1.

Design Speed

The design speed will affect such factors as the distance required for visibility on both horizontal and vertical curves, the minimum radius of curvature of the road, superelevation, and the length of transition curves.

These factors in turn have a bearing on costs and it is therefore worth while to give some thought to the most appropriate design speed. There are several cars now in production capable of speeds in excess of 100 miles per hour but it seems unlikely that many drivers or their vehicles will be capable of sustaining such speeds for any great distance. It is not necessary

Fig. 4


CALIFORNIA BEARING RATIO
2 3 4 5 6 7 8 9 10 15 20 30 40 50 60 70 80 90 100
COMBINED THICKNESS OF SURFACE AND BASE: INCHES
0 5 10 15 20 25 30 35
4,000 lb. wheel load
7,000 lb. wheel load
15,000 lb. wheel load
25,000 lb. wheel load
GENERAL SOIL RATING AS SUBGRADE OR BASE MATERIAL
Very poor
Poor
Fair
Good
Excellent
2 3 4 5 6 7 8 9 10 15 20 30 40 50 60 70 80 90 100
CALIFORNIA BEARING RATIO
100 150 200 250 500 800
MODULUS OF SOIL REACTION K IN LB./SQ. IN./INCH.
(SATURATED SOIL IN PLACE)

THICKNESS OF ROAD CRUSTS

that they should do so for the motor-roads to be successful, since they are not intended as race tracks, but on the other hand they will fall short of one of their main objectives if traffic cannot safely maintain a considerably higher average speed than on the classified road system. The design should allow a good steady average to be achieved without the need for excessive maximum speeds.

In the United States of America it has been found that most cars travel at about 45 to 50 miles per hour under free-flow conditions, and a design speed of 70 miles per hour in rural sections is now regarded as ample. This is considerably less than the design speeds recommended for the German motor-roads before the 1939–45 war which were 100 miles per hour in " lowland " country and 62·5 miles per hour in " high mountainous " country, but it is probable that these speeds would be reduced for construction at the present time.

The speed value of a motorway should not vary to any appreciable extent and unless the terrain is very difficult a design speed of 70 miles per hour is regarded as suitable for Great Britain.

Minimum Radius of Curvature

Curves of large radii are desirable and so far as practicable the minimum radius should be 2,865 feet, that is to say, a 2-degree curve.

In very hilly country it may not be possible to work to this radius without heavy earthworks and some relaxation is permissible in such cases. For instance on the most difficult section of the proposed motorway through the Lune Valley in Westmorland, the minimum radius will be 1,508 feet (3 degrees 48 minutes curve) and this is about the limit.

Visibility

The visibility distance in the vertical plane over the undulations of the road and in the horizontal plane round a curve is the distance a driver needs to stop with due allowance for reaction time and braking efficiency.

Vertical visibility is measured between points 3 feet 9 inches above the carriageway which is the assumed eye-level of the driver and horizontal visibility is measured on the centre line of the carriageway. For a speed value of 70 miles per hour on roads with dual carriageways, Ministry of Transport Memorandum No. 653 [9] gives a sight distance of 650 feet.

The visibility distance on horizontal curves should be wholly within the limits of the highway, so verges and the slopes of cuttings on the inside of a curve should not be planted with trees or shrubs which, at maturity, may obstruct the view of drivers.

Superelevation and Transition Curves

The amount of superelevation to be applied on curves depends upon the design speed and the degree of curvature. All curves sharper than 1 degree should be superelevated and the range of superelevation varies from the natural cross-fall for the surfacing material to about 1 in 14. A steeper cross-fall would cause difficulties under conditions of snow and ice.

The elimination of adverse cross-fall and the application of the required superelevation should be achieved gradually throughout the length of the transition and it can be done in different ways, according to the point chosen for the rotation of the carriageway. It is usual in Great Britain to raise the outer channel above the inner channel to avoid a dipping appearance and possible drainage difficulties. There are cases, however, where it will be more economical to drop the inner channel or alternatively to rotate the carriageway about some other point. Such a case might be where the outer side of the road is on embankment and curving round the nose of a hill with superelevation contrary to the slope of the ground, or where a necessary bridge clearance can be obtained more easily by this method.

The need for a transition curve to connect a straight section of road to a circular arc is now generally accepted since it facilitates the application of superelevation, improves the appearance and allows a driver to turn his steering wheel gradually. This last point is considered to be of minor

importance by J. J. Leeming [10] who has carried out a wide range of experiments on the driving of vehicles round curves.

The essential requirement of a transition curve is that the radius should decrease gradually from infinity to the radius of the circular arc, and the most frequently used curve to meet this condition is perhaps the spiral. The lemniscate and cubic parabola (within certain limits) are also suitable and each has advocates who have written at length in support of their choice.

The correct length of the transition curve has also been the subject of controversy but, provided it is sufficiently long to permit the required superelevation to be applied without causing discomfort or a bad appearance, the exact length is not critical.

The following rule is used in America: "Superelevation shall be attained gradually and in such manner that the difference in slope between longitudinal profiles separated by the width of one lane shall be not greater than 1 in 200."

The length of the transition is frequently calculated by Shortt's theory [11] which gives it as $\frac{3{\cdot}15V^3}{CR}$ where V denotes the velocity in miles per hour, C the rate of change of radial acceleration in feet per second ^{3} and R the radius in feet. The difficulty here is to assign a value to C since Shortt's figure of 1 foot per second,^{3} applicable to railways, is generally recognized as too low for roads, giving transitions of longer length than they need to be. Shortt stated that a radial acceleration of 1 foot per second ^{3} was the maximum that would pass unnoticed but experiments have shown that a value of 2 feet per second ^{3} does not cause any great discomfort to driver or passengers in a car.

It is considered that a value of $C = 1{\cdot}5$ is quite suitable if Shortt's formula is used and it gives a reasonable length of transition which complies with other requirements. The following table calculated on this basis gives a guide to the lengths of transition curves for various radii and also the superelevation required. It is interesting to note that the same lengths of transition are obtained for $V = 61$ miles per hour and $C = 1$, and also for $V = 77$ miles per hour and $C = 2$.

TABLE 1

Degree of curve :	Radius : feet	Approx. length of transition : feet	Superelevation
1 degree	5,730	125	1 in 45
1 degree 30 minutes	3,820	187	1 in 35
2 degrees	2,865	250	1 in 26
2 degrees 30 minutes	2,292	312	1 in 21
3 degrees	1,910	375	1 in 18
3 degrees 30 minutes	1,637	437	1 in 15
3 degrees 48 minutes	1,508	478	1 in 14

Subject to the limits already mentioned, the superelevation is calculated so that a centrifugal ratio of 1 : 4 is not exceeded, and the centrifugal force of a vehicle travelling at 40 miles per hour, that is to say, about three-fifths of the design speed, is counterbalanced completely. Above this speed up to 70 miles per hour a driver can rely safely on the friction between the wheels of the vehicle and the road surface provided the surface is not covered with ice.

American practice is to calculate superelevation so that it is sufficient to counterbalance completely the centrifugal force of a vehicle travelling at three-fourths of the design speed, which gives a somewhat higher rate. The maximum superelevation recommended in America is 0·12 foot per foot (1 in 8·33) except where snow and ice may be expected to cause a frequent slippery condition of the road surface, in which case the maximum superelevation is 0·08 foot per foot (1 in 12·5).

When considering superelevation, it is a help to draw a longitudinal section with a greatly exaggerated vertical scale showing the relationship of the four channels to the normal grade line which for this purpose can be represented as a straight horizontal line. It facilitates a smooth change over at reverse curves and the extra gradient along transitions is easily checked.

Gradients

Ministry of Transport Memorandum No. 653 states that " A gradient of 1 in 25 (in lieu of the 1 in 30 specified in Memorandum 575) should ordinarily be regarded as the maximum, but in hilly country a heavier gradient may have to be adopted."

In the case of the proposed motorway through the Lune Valley in Westmorland, which is perhaps one of the most difficult lengths likely to be encountered in this country, it has been found possible to keep within the maximum of 1 in 25 and gradients steeper than 1 in 30 are very rare and of short length.

Cross-fall

Each carriageway should have a uniform cross-fall, according to the surfacing material, sufficient to throw off rain water. On a normal straight length of road the cross-fall will be outwards from the central reservation and since there is a flush verge and no kerb the surface water will flow away to the drains in cuttings or over well consolidated embankments where the road is on filling. If there is any risk of surface-water collecting in sufficient quantity to cause erosion, special precautions will be necessary.

It is easier to increase the width of dual carriageways, should this become necessary, if they have a straight cross-fall.

Junctions

A good design must eliminate traffic cuts so far as possible and regulate the flow of traffic without slowing it down to such an extent that congestion

is caused. In the first place there should be no connexions to the motorway except at points carefully chosen to give maximum benefit to traffic. All minor roads therefore will be carried over or under the motorway according to the levels and other circumstances at each site.

If regrading is necessary it is usually cheaper to alter the comparatively narrow minor road and, whilst the full headroom of 16 feet 6 inches is necessary for all bridges over the motorway, it may be possible sometimes to agree to a smaller clearance when the minor road passes under the motorway.

The spacing of junctions requires careful consideration in the light of the figures for traffic volumes in the vicinity. It would be in the interests of economy and safety if junctions could be more than 5 miles or so apart but in a well developed country there are roads of some importance every mile or two and nearly all have some claim to be connected to the motorway. No hard-and-fast rule can be laid down as to spacing, but the number of junctions and their position must be chosen so as to make the motorway fully effective with a minimum of interference to the free flow of traffic.

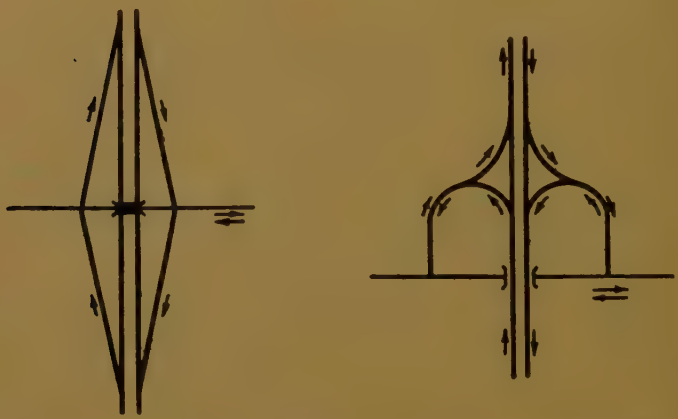
A good type of junction at the start or termination of a motorway where it joins the classified road system is a roundabout, since it compels traffic to reduce speed to a reasonable figure and eliminates cuts by substituting suitable weaving angles. The design depends on the lay-out and widths of the converging roads and the limits which may be imposed by reason of the difficulty and cost of acquiring land. In some cases the volume and distribution of traffic may be controlling factors. The diameter of the island should not be less than 180 feet and preferably greater, if land is available.

A fly-over of the clover leaf type is an excellent form of junction since it eliminates all right-hand turns and permits a lane capacity very near to free flow conditions. It requires a large area of land, however, in the region of 24 acres, and the cost is inevitably high. It is unlikely that such elaborate junctions will be adopted in Great Britain and, as an alternative, each junction should be tailor-made to fit the conditions of alignment, traffic, and topography at the particular site. It is not so much a case of selecting one or other of a number of standard designs but rather a decision on the principles to be applied. For instance, although traffic cuts on the high speed road must be eliminated it may be possible to allow traffic cuts on the minor road or alternatively to introduce signal control. Two-way traffic on the ramps may be possible and if so it should lead to considerable economy and saving of land. A decision on these points will indicate the most suitable form of junction. It may be a roundabout with the motorway flying over (or under). This causes negligible interference with the through traffic since all exits from and entrances to the motorway are made in the correct direction, by way of link roads provided with deceleration or acceleration lanes, whilst the roundabout takes care of all turning movements on a different level. This type requires very little extra land over

the normal roundabout but the disadvantage is that two rather expensive bridges are necessary and care is required in the lay-out to see that a clear view of traffic on the link roads is not obscured by the bridges.

A further modification is the single-bridge lay-out with four one-way link roads or two two-way link roads, as shown in *Figs 5*. Here again,

Figs 5



LINE DIAGRAMS SHOWING CONNEXION OF MINOR ROAD TO MOTORWAY

there is little interference with the main traffic but there is the obvious defect that turning-right traffic is unavoidable on the minor road. For this reason it is a lay-out which would not be satisfactory where such movements are heavy.

The gradient on link roads should not exceed 1 in 20 and acceleration lanes should be provided, permitting drivers to attain a speed of 70 per cent of the design speed of the motorway before entering the main highway. The rate of acceleration is assumed to be 1·5 foot per second per second. It is reasonable to assume also that drivers travel at not more than 70 per cent of the design speed of the main road when entering a deceleration lane and the rate of deceleration may be taken as 5 feet per second per second.

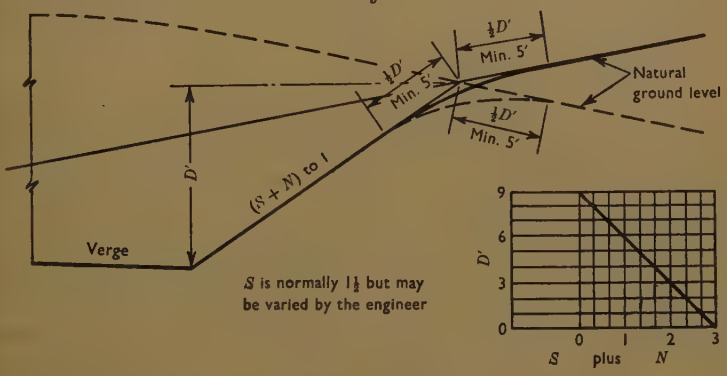
Treatment of Slopes

If the slopes of cuttings are rounded convexly at the top they have a better chance of merging into the landscape, and for the sake of appearance shallow cuttings should have easier slopes than deep cuttings. The maximum slope of the soil, S to 1, is suitable for cuttings 9 feet or more in depth (subject to any limiting factors imposed by engineering considerations), $S + 1$ to 1 for cuttings 6 feet deep, and $(S + 2)$ to 1 for cuttings

3 feet deep. The relationship between slopes and depth of cutting is shown in *Figs 6.*

The slopes of embankments should be concave at the base between points 8 feet along the natural ground and 8 feet up the slope. A slope of 3 to 1 is appropriate for heights of bank up to 6 feet, and for embankments over 6 feet high the 3-to-1 slope should be carried to a height of 6 feet; from this point upwards the slope may be the maximum for the soil with concave rounding introduced at the change of slope.

Figs 6



TREATMENT OF SLOPES OF CUTTINGS

The slope of a cutting is chosen by trial and error so that the relationship between D and N is as shown on the graph

It will be noted that the only sharp edges are the shoulders of embankments and the toes of the slopes in cuttings. All other changes of slope and junctions with the natural ground are rounded on the cross-sections, unless a ditch or some other feature prevents it.

This treatment results in longer slopes than usual and in the interests of agriculture the desirability of allowing the landowner to re-use as large a part of the area as possible must be kept in mind.

Unless there are special reasons such as the need for a ditch or watercourse at the foot of an embankment it is suggested that complete acquisition of land should be up to the point which would have been the bottom of the slope if no rounding had been introduced, that is, from the top of the embankment to the point where a straight slope of S to 1 cuts the existing ground level. The remaining width from this point to the point where the bottom of the rounded slope merges into the existing ground level can be dealt with normally by means of a licence (" temporary easement ") enabling formation work to be carried out but at the same time leaving the land in the possession of the landowner for agricultural use. Boundary stones at suitable intervals along the slope will mark the boundary line of the land conveyed for road construction.

There will be places where the rounding of embankment slopes will be of no great amenity value and factors to bear in mind include the general character of the land, the size and disposition of the plots, the length and depth of the particular embankment, and the positions from which the embankment will be visible.

Slopes should be soiled and seeded or, in appropriate cases, turfed or planted with suitable shrubs.

Embankments will usually be formed by depositing suitable excavated material in layers not exceeding 6 inches depth after final compaction. On steep sloping ground it may be necessary to bench the surface of the ground and soil tests may reveal that special precautions are necessary, both in design and actual construction.

The character of the soil has an effect on the balance of cut and fill according to the amount of bulking or shrinkage to be expected, and the soil tests are of value when considering this. A mass-haul diagram is required to determine whether or not too much material will be wasted or if the extra filling required will be excessive. It may be possible to overcome a shortage of filling by widening or " daylighting " any cuttings which happen to be in suitable material, but failing this it will be for consideration whether the profile ought to be adjusted or filling brought in from a distance. It will not always be possible to obtain an exact balance of cut and fill in the case of new roads constructed to the high standards required for a motorway, but it must be the constant aim of a good design to reduce the need for borrow-pits and spoil-heaps.

Land Severance

One of the greatest obstacles to the construction of motorways is the problem of land severance. Mention has already been made of the need for a plan of farm boundaries in the early stages and much can be done to minimize the effects of the new road by a careful study of this plan. In Great Britain, however, the farm units are often so small and of irregular shape that a line planned along the boundary of one farm may pass right through the middle of the next.

A great deal of time must be devoted to finding the best compromise in consultation with local interests and keeping in mind all the engineering problems and requirements.

It is frequently suggested that the road might run alongside a railway to avoid severance and this may be the best solution in some cases. Generally speaking, however, difficulties will arise for one reason or another. It will probably be necessary to cross the railway at some point and this will entail a wide sweep to get a bridge at a reasonable angle. This may cause more serious interference with the land than a line farther away from the railway in the first place, but perhaps the greatest problem will be how to deal with existing roads crossing the railway which must also cross the new road. The headroom over the railway will probably be much less

than the 16 feet 6 inches required over a motorway, and the greater span of the road bridge may call for a greater construction depth in addition.

It is clear that the closer the road is to the railway the more difficult this problem becomes, and coupled with the nuisance of smoke from trains and the risk of headlights confusing drivers of trains or coloured signals on the railway confusing drivers on the road, there is seldom any advantage in following such a line.

Another solution, which does not always meet with agreement from the farmers concerned, is an exchange of land. Unfortunately it does not work well in practice and a number of undercreeps and overpasses will have to be provided.

The following standards are suggested for these features :—

Undercreeps

Cattle—small herds of say twenty cows	14 feet wide × 8 feet high
larger herds	18 feet wide × 8 feet high
Ordinary farm implements	15 feet wide × 14 feet high
Maximum gradient of approach	1 in 10 with suitable short vertical curves
Surface of concrete	Rough spade finish

Cattle creeps must be wider than ordinary farm gates owing to the risk of injury if cattle overcrowd a narrow tunnel.

The width given for ordinary farm implements allows for the wide type of drill and similar equipment and the pusher-type combines ; the height allows for an ordinary steam threshing set. There may be exceptional cases where 16-foot combines are used, necessitating a width of 18 feet.

Overpasses

Width	15 feet in the clear
Headroom	16 feet 6 inches
Weight to be carried	8 tons maximum
Maximum gradient	1 in 10 with suitable short vertical curves

If the new road unavoidably prevents cattle reaching their source of drinking water it will be necessary to provide an alternative supply.

Drainage

The carriageways of the new road will create new impermeable areas and the extra run-off should be collected into the main watercourses whenever possible. In cuttings the surface water will be collected by means of a ditch or pipe drain in each verge and a drain in the central reservation will be provided only when superelevation makes it unavoidable.

It is important to consider the effect of the new road on existing drainage systems, and if under-drainage in a field is severed it will be necessary to provide new outlets for any portion cut off from the original outlets. In the case of tile drainage this may consist of a tiled main of adequate size to take all laterals. Similarly in the case of mole drainage the outlet would probably be a suitable tiled main covered with porous filling, any mole drains blocked by the excavation of the main drain being located and cleared before back filling.

Where a number of ditches are cut off by the new road it is usually cheaper to collect the water by new roadside ditches terminating at one large culvert rather than to build a culvert for each. Culverts and small bridges must be of sufficient size to deal with flood waters without any serious hold-up. The size of existing culverts and watercourses in the vicinity will be a good guide but it is advisable to calculate the flow from considerations of the catchment area and rainfall intensity to be expected. The larger river bridges will frequently require flood arches and these can often serve as cattle creeps or other accommodation connexion between lands severed by the road.

It is essential to maintain close liaison with the Engineer to any River or Drainage Board and the Land Drainage Engineers of the Ministry of Agriculture and Fisheries. Incidentally, any interference with fishing rights should be guarded against. This may come about by a new bridge obstructing the flow of a stream, by pollution during construction, or by subsequent washings from the surface of the road.

Most highway engineers will be familiar with this latter problem and the precautions necessary, such as the use of bitumen or a brand of non-toxic tar specially developed for the purpose.

Gullies will not be used on motor-roads except at bridges or for some special reason and then every effort should be made to keep the surface of the carriageway clear of gulley gratings by placing them behind the kerb line or in the verge with side entrances.

Snow Clearing

Difficulties arising from heavy snow falls will be minimized by the comparatively easy gradients proposed for motorways. Snow ploughs will operate without difficulty and the verges provide ample space to store snow. The road should be designed as far as possible so that the wind will clear snow from it, and for this reason a low embankment may be advisable in open country. Deep cuttings should be avoided on high ground when snow is likely to drift, and if a road is to run along the slopes of a valley there is an advantage in constructing it on the side which gets the most sun. If snow fences are required, a suitable type is cleft chestnut 4 feet high with pales 2 inches apart. The bottom of the fence should be 6 inches above the ground and it will probably need to be sited some 15 to 25 yards back from the highway boundary.

Bridges

The conditions at many of the sites for overbridges will be sufficiently similar, in span and vertical clearance at least, to permit a certain amount of standardization. Any variation in the physical characteristics of the site, however, will provide the opportunity for variations in design to prevent monotony. Considerations of economy tend towards a four-span structure with piers in the central reservation and the verges so that generally this will be the most suitable type of overbridge. The lay-out of a motorway in cross-section does not lend itself to three-span construction and where there are objections on aesthetic or other grounds to the four-span structure, a single portal frame in either steel or reinforced concrete may provide a pleasing solution. Other types are, of course, not excluded.

Underbridges will generally be of shorter span and less conspicuous, and cattle creeps can be standardized in the majority of cases. The advice of the Royal Fine Art Commission is available to find suitable treatment for the requirements of any site.

Preliminary Drawings

The size and shape of drawings used in the preparatory stages are largely matters of personal taste but it is essential to be able to examine long lengths of both plan and profile at the same time, because a slight amendment may affect the line for a considerable distance either way. Long strip drawings are therefore preferable to a number of single sheets, and the length can be accommodated either by rolling or folding in concertina fashion.

For the " scheme " under section 1 of the Special Roads Act the Minister of Transport has issued Regulations which require " a map on a scale of 6 inches to the mile on which there shall be indicated the centre line of the special road authorized by the scheme to be provided along that route."

The ultimate centre-line should be shown by a continuous black band not more than $\frac{1}{16}$ inch wide and the plan must be certified up to date within 220 feet of the centre-line on each side of the road.

Where the proposed special road is more than 10 miles long, a key plan to a scale of 1 inch to the mile is also required, showing the centre-line by means of a band of red colour about $\frac{1}{32}$ inch wide.

In addition, a copy of the $\frac{1}{2500}$ plan and longitudinal section will be required if these have not been supplied already.

Orders under Section 3 of the Act concerning side-road proposals need plans and sections to a minimum scale of $\frac{1}{2500}$ and a separate 6-inch plan will serve as a key plan for these.

Contract Drawings

The following drawings will be required :—

Road Works

Key plans
General plans and longitudinal sections
Cross-sections
Drainage plans and longitudinal sections
Road crossings and junctions
Mass-haul diagram
Typical cross-sections in cut and fill, etc.
Details, such as road-slab reinforcement, concrete surrounds to pipes, catchpits, fencing, and gates.
Culverts
Soil survey

Bridge Works

Key plan
Detail plans
Longitudinal sections
Cross-sections
Structural details
Levels should be related to Ordnance Datum and foundation details should include data on boreholes and trial pits where necessary.

Conclusion

The design of motorways covers a wide range of interesting subjects and it has not been possible to cover them all completely within the scope of a single Paper. In spite of this the Author hopes that the Paper will be of interest to engineers and will form the basis for discussion of a type of road new to Great Britain, even though financial limitations may not permit a practical application of the principles for some time yet.

Acknowledgements

The Author wishes to thank Mr E. B. Hugh-Jones, M.C., B.Sc., M.I.C.E., Chief Engineer of the Ministry of Transport, for permission to present this Paper and also many colleagues at the Ministry for help in preparing it.

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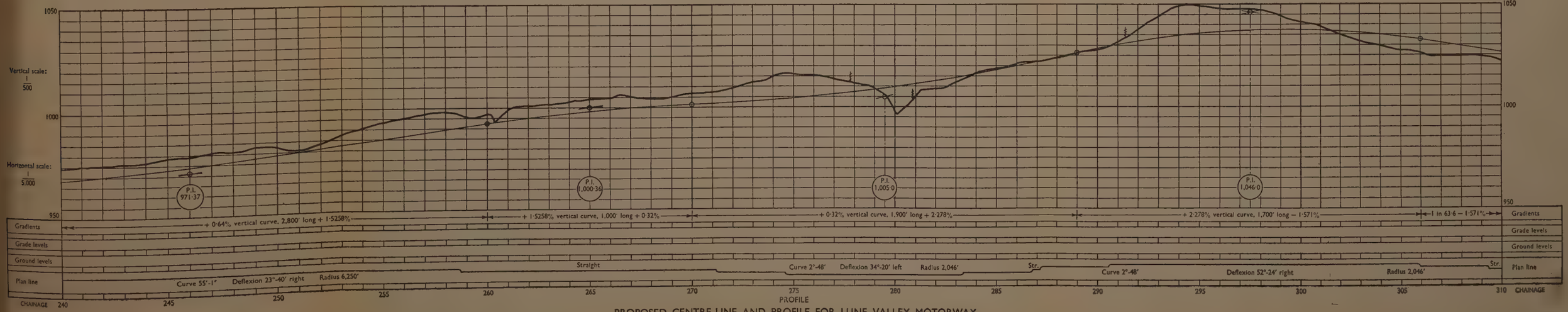
FIGS 2

PLAN


Vertical scale: 1/500
Horizontal scale: 1/5,000
P.I. 971·37
P.I. 1,000·36
P.I. 1,005·0
P.I. 1,046·0
+ 0·64% vertical curve, 2,800' long + 1·5258%
+ 1·5258% vertical curve, 1,000' long + 0·32%
+ 0·32% vertical curve, 1,900' long + 2·278%
+ 2·278% vertical curve, 1,700' long − 1·571%
1 in 63·6 − 1·571%
Gradients
Grade levels
Ground levels
Plan line
Straight
Curve 55'-1" Deflexion 23°-40' right Radius 6,250'
Curve 2°-48' Deflexion 34°-20' left Radius 2,046'
Str.
Curve 2°-48' Deflexion 52°-24' right Radius 2,046'
Str.
CHAINAGE
240 245 250 255 260 265 270 275 280 285 290 295 300 305 310

PROFILE

PROPOSED CENTRE-LINE AND PROFILE FOR LUNE VALLEY MOTORWAY

T. E. HUTTON

The Institution of Civil Engineers. Proceedings, Part II, October 1953

WILLIAM CLOWES & SONS, LIMITED: LONDON

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The Paper is accompanied by six sheets of diagrams from which the folding Plate and the Figures in the text have been prepared.

Discussion

Mr R. J. Samuel said that it was possibly true that the Paper gave the views of the Ministry of Transport, but those were not unchangeable.

The Author had said that he wondered when the motorways would be constructed. Obviously, it had to be borne in mind that there was a lot of leeway to be made up in the maintenance of existing roads and small works, which would take a large proportion of the money when some was provided. When money was available, perhaps by-passes and small sections of the roads would be constructed on motor-road lines under the

Special Roads Act, and it was therefore desirable that a decision should now be reached as to the best form of construction.

Mr Samuel then raised two points concerning construction, observing that the views he expressed were his own, rather than those of the Ministry of Transport. On pp. 720 and 722, the Author had recommended that there should be a hardstanding on the side verges, with a cross-fall of 1 in 15, for the benefit of drivers who had to make an emergency stop. He was not at all sure that, if one had to leave the carriageway in an emergency, it would be too pleasant getting on the 1 in 15 slope. It was worth considering if the hardstandings ought not to be level, which would enable the side verge to be reduced. He knew that that would mean more conventional drainage. The design of the motorways largely followed the Continental pattern, and not all imports into Great Britain were beneficial. He suggested that a little more thought might be given to that matter.

His next point was one which would probably cause some consternation. Was a dual carriageway necessarily the best form of construction ? The Author had said that dual carriageways were regarded as essential and that whilst only one carriageway might be constructed in the first place, ultimate plans should provide for dual carriageways so that the passing streams of traffic were separated in the interests of safety.

Mr Samuel believed that dual carriageways were first advocated in a memorandum issued in 1935, where it was stated that if the traffic flow was more than 4,000 (since raised to 6,000) vehicles per day, dual carriageways were advised. It had been assumed ever since that that was sacrosanct ; but there was no proof that dual carriageways were safer than single carriageways. An instance had come to his notice a short time ago which had startled him. Several miles of a 40-foot carriageway on a trunk road carrying a heavy volume of traffic had been converted into dual 22-foot carriageways with a 6-foot strip in the middle, and the accident rate there had risen, whereas on the adjacent section which remained a single carriageway the accident rate had not gone up. He did not know whether that unfortunate trend would continue over a long period or whether it was true of all roads in Great Britain. There were a number of 40-foot and 30-foot, single- and dual-carriageway roads, and he felt that an investigation should be made into the accident rates and the carrying capacity of those various forms of road so that, before any of the motor-roads were constructed, it could be confirmed that the best, cheapest, and safest form of construction was being adopted.

If by chance it was established that a 40-foot four-lane carriageway was as good as, or better than, a dual carriageway, the 93-foot width of lay-out could be reduced to about 60 feet, with a saving in land, earthworks, and construction. It should not be forgotten that, in the present hard times, road engineers were like manufacturers and had to sell their products, and the cheaper they were, the more easily would people buy them. If a limited sum of money was available, the cheaper the form of construction

commensurate with sound engineering practice, the more miles of motor-road could be constructed.

Colonel G. T. Bennett observed that the difficulties of land appropriation seemed to be interfering with every kind of activity—not only road-building but housing and everything else. Every piece of land that one looked at was " the best agricultural land in the country." He believed that he was correct in saying that less than 1 per cent of the land of England was taken up by highways, and considering that nothing in the country could function at all it if were not for the roads, he felt that that figure was not excessive. If 1,000 miles of full-width motorway were constructed, it would take 0·03 per cent of the country's land, which was a quite negligible amount. That was a most important point to be borne in mind by engineers, who should not meekly accept the agriculturists' objections as to the vast amount of land required for motorway construction.

He remembered being involved in an argument, just after the war, about a diversion to avoid an aerodrome which had been built across the line of a trunk road. One possible method was to use an existing road, widening it, and the other was to construct a new road which would have been shorter by half a mile. It was not difficult to make a reasonable calculation as to what the shortening would have meant in saving of transport costs ; in fact, assuming a very low figure for the ton-mile cost of transport and capitalizing the annual saving, a saving equivalent to a capital sum of £1,000,000 would be achieved if the shorter route were adopted. The objection to the proposal was that farm land would have been severed ; but how many farms could be bought outright for £1,000,000? If manufacturers' costs could not be reduced by cutting transport costs, then Britain would grow its food but grow it very dearly ; only half Britain's food was home-produced anyway. As a nation, the British had to rely primarily on the fact that they manufactured, and manufactured cheaply, and exported in order to buy their food. If that were forgotten, there would be sufficient food but little else, and it would be very dear food at that.

With reference to alignment, Colonel Bennett put in a plea for occasional very long straights. The last thing he wanted to see was the English road always going perfectly straight like the Roman roads, for the practice in England of following the contours provided half the attraction of the countryside to motorists, but, speaking for himself, he liked occasionally to get on to a 10-or 20-mile straight. Some of the straight roads up to Newmarket or across Wiltshire were very pleasant. When there was an opportunity to build a straight road of reasonable length he did not see why it was necessary to construct sweeping curves which the contours did not require.

However the foundation of the roads was built, whether it was of concrete or a flexible construction—and he would not take sides on that question ; he was sure that some would be one way and some the other—he

hoped that the roads would be finished with a " black " top. He did not believe that a beautiful road could be built in exposed concrete ; nothing could make concrete surfaces look well in Great Britain.

He wondered whether the rounding of slopes in cuttings and embankments was really necessary. He had built many embankments and cuttings with straight slopes and once they were planted they looked well. He could not see the need for the extra land and cost, and the extra work and difficulty from the point of view of the engineer in setting-out.

Mr S. M. Lovell said that he wished to make one point in connexion with the safety factor which seemed to be quite predominant in the construction of the new motor-roads. In the Paper and in his introductory remarks, the Author had referred to the fact that there would be no kerbs but that there would be marginal strips, and he had referred in particular to a marginal strip 1 foot wide of a colour contrasting with that of the carriageway, especially at night. Mr Lovell held a purely personal view that the definition of the road edge was one of the most important factors, which appeared to have been forgotten. Certainly it had not been given the attention which it deserved ; it was a vitally important matter in relation to safety on motorways in particular and highways in general. He did not believe that 1 foot was anything like a sufficient width. The idea should be extended, and something very much bolder should be adopted.

The matter of hard shoulders arose from the fact that there would be a flush carriageway channel margin of more or less the same level, there being, in fact, no vertical rise. Instead of building hard shoulders 4 feet 6 inches wide, the opportunity should be taken of making them sufficiently wide so that traffic of all sorts could pull off the road if it wanted to. Those who had built roads to that type of design knew that traffic would pull off the road. It was rather " spoiling the ship for a ha'p'orth of tar."

Another important point arising from his personal experience in connexion with flush-margin construction was that subsequent to altering a road to that type of construction the non-productive maintenance costs on the road had dropped by 75 per cent, which was a striking figure. The road never had to be swept now, for it cleared itself, which was an important point. The gravel which was put down in the winter for gritting was cleared to the side by the traffic itself. The more it was possible to reduce the non-productive costs, the more money there would be available for future construction work.

He believed that about 4 or 5 years previously, the Ministry of Transport had issued its recommendations concerning the types of foundations to be used for motor-roads. He had not had time to refer to them, and he wondered if the Author could tell him what they were. He hoped that the Ministry would consider the granular type of foundation—that was, building up on Macadam's principles rather than on those of Telford, which consisted of building up with large pieces of stone. The Macadam

method would utilize local aggregate more than did the Telford type of foundation.

Mr James Drake observed that, on p. 712, under the heading " Preliminary Considerations," the Author had referred to the siting of motorways. Mr Drake entirely agreed with the Author that motorways generally should be sited close to large centres of population. What a great benefit it would be if all the motorways shown in *Fig. 1* were built. However, in spite of the benefits from the peace-time and war-time points of view, he was afraid that the full programme would never be completed unless the first lengths to be constructed were very carefully chosen. He felt that if the first lengths did not attract a great deal of traffic and also save a large number of accidents, the motorway programme would just wilt and die.

To illustrate his point, he displayed a slide (reproduced in *Fig. 7*) which showed the large towns in Lancashire. The diameters of the outer circles were proportional to the population of the towns, and the diameters of the inner black circles were proportional to the traffic entering the towns. The Figure indicated immediately which towns in Lancashire had a large proportion of by-passable traffic, namely, Preston and Lancaster. Lancashire had carried out a very careful traffic survey to find out what traffic would use a north-south motorway through the county. That motorway was shown by a broken line by-passing Wigan and Preston.

The survey, based on present traffic figures, had shown that the number of vehicles on the length adjacent to Preston would be 3,600 during the peak hour, while the figure on the length just south of Wigan would be about 750 vehicles per hour. He hoped that the Author would agree with him that it would be inadvisable, indeed foolish, to construct the Wigan length of the motorway before the Preston length.

On p. 717, reference was made to soil survey. The advantage of carrying out a soil survey had already been proved in Lancashire, where one had been in progress for a considerable time. One hundred and eleven boreholes had been sunk on the line of the motorway to a total depth of about 2,600 feet.

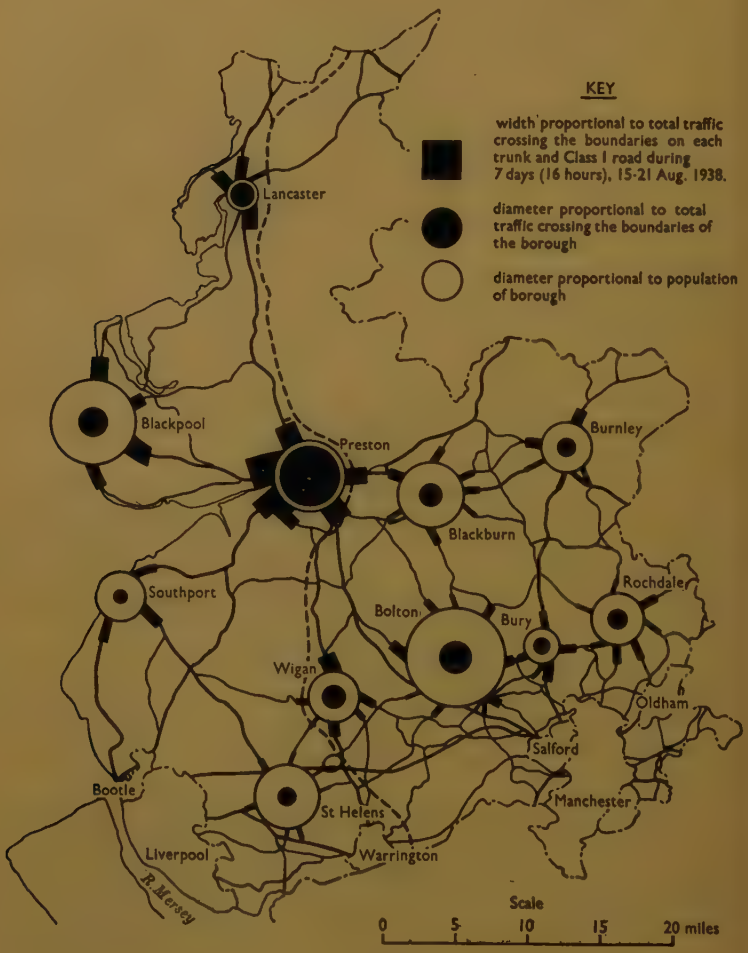
Mr Drake's second slide showed the California Bearing Ratio of various samples tested so far. Roughly 40 per cent had a C.B.R. of between 2 and 3 per cent. That was because the siting of the motorway was predominantly on clay and boulder clay. Fortunately—from a road construction point of view—Lancashire had a large number of burnt-pit-shale heaps which could be used as a sub-base. The soil survey had shown that there was no need to vary either the intended horizontal alignment or the profile, but it would have very valuable results in other ways.

On p. 718 there was reference to fitting the road to the landscape, and to flowing alignment. He was of the opinion that with the very flat curves required by the Ministry for motorways there was little danger of getting into trouble from an amenity point of view. That did not mean that all the research into flowing alignment could be ignored, but it should

not be treated too rigidly or it would put up the cost of the road to such an extent that the work would never be carried out.

His next four slides showed a model of the motorway in Lancashire

Fig. 7



RELATIVE POPULATIONS OF, AND TRAFFIC ENTERING AND LEAVING, THE COUNTY BOROUGHS AND LANCASTER

just south of the Westmorland length dealt with by the Author. The Lancashire Section of the Council for the Preservation of Rural England had agreed that the motorway, according to the design shown on the model, would not detract from the amenities of a very pleasant part of the county.

Mr Drake appealed to the Author to amend his views with regard to the suggestion to allow two-way traffic on the ramps at certain junctions in order to save expenditure and land.

Despite what Mr Samuel had said about dual carriageways, he was still a firm believer in them. Mr Drake had calculated that if single carriageways were adopted, the saving in land would be $\frac{1}{5}$ acre per junction and the saving in cost would be about £2,000, and he considered that that trivial saving, which would reduce the safety and attractiveness of the entrance to the motorway, was simply not worth while.

He agreed with Colonel Bennett—and he was sure that the Author would also agree—that if one wanted to save costs on the motorways, it would be preferable to dispense with the rounding-off of the bottom of slopes on embankments. That would prevent the disturbance of 200 acres of land in Lancashire alone, and he did not believe that it would ever be noticed once the hedges were planted.

Mr J. E. Cardell said that he wanted first of all to emphasize the usefulness of contours. There was still a tendency among road engineers to think that successful road location was a question of a flair or a gift of God, or solely a matter of personal judgement. He was firmly of the opinion that even when all the information available had been obtained there was still scope for the exercise of all the judgement that any one of them had. That applied particularly to the use of contours. With many plans, the project could not be visualized in relation to the detail of the terrain, but with contours that was possible, and a number of different lines could be tried in order to determine which was the best. It was very difficult to assess the merits or otherwise of road lines without contours and sometimes one suspected that they had been sited by guesswork.

With reference to fitting the road to the landscape and the relation between the horizontal and vertical curves, when Mr Howarth and he had presented their Paper[18] they had suggested that something on the lines of a really large-scale model should be constructed, which would enable the inter-relation of the curves to be properly explored. He still thought that that would be a good thing. Rules had been evolved which were safe and foolproof, but it had never been demonstrated that they were the most economical.

Reference had already been made to the question of hard shoulders. With hard shoulders, were lay-bys really needed ? After all, if a car had a burst tire, it could not run any distance to a lay-by but had to stay where it was. The question arose, therefore, of whether or not it would be too costly to widen the hard shoulders ; even if a big vehicle could not draw completely clear it might be able to draw partly clear.

If lay-bys were to be incorporated, was it right to have them at the bottom of a hill ? That would enable vehicles to coast down to them, but there were several adverse factors. It was often found that the softest

[18] See ref. 1, p. 736.

ground was in the valley and the hardest at the top of a hill. A good view could be obtained from the top of a hill, and lorry drivers often selected stopping points on high ground rather than on low ground. Another factor was that a vehicle might get over-heated through climbing a hill and the driver would want to stop at or near the top to allow the engine to cool. Again, for starting off from cold it was advantageous to have a falling gradient to begin with, rather than a rising gradient to ascend. For those reasons, he suggested that if lay-bys were necessary, hill bottoms should be avoided rather than selected.

He had another point to make concerning the idea of locating major roads alongside railways. He had seen that recommended many times but in his experience he had never found a case where it was a feasible proposition for any length. In difficult country, for example, a point would be reached where the railway line had gone into a slope as far as possible, and if the road was on the up-hill side the proposition was not a practical one, for to cross over it was necessary to make a big swing outward. Various other difficulties arose and he had never found it feasible in practice, but if anyone had done so he would be interested to hear about it.

Mr G. C. Wilson observed that, with regard to soil surveys, the Author had advocated a logical approach employing a preliminary exploration to give general data on the ground conditions existing over a proposed road line. On the whole, his outline of the scope and methods of such an exploration was reasonable, but Mr Wilson doubted if on any major scheme hand auger boring and identification tests alone would ever be sufficient.

Under favourable conditions, geophysical methods could be of great assistance on extended sites such as roads. They were not precise methods, but they enabled an approximate rock profile to be obtained quickly. Since depths down to, say, 50 feet could only be measured to within plus or minus 10 per cent, frequent boring and drilling had also to be carried out if it was necessary to determine accurately the rock surface. The results of a geophysical survey could be used to locate boreholes where they would give most useful information. Such a survey could also indicate if there was any likelihood of rock excavation being required. If so, the possibility should be considered of modifying the vertical alignment so that the rock was avoided and expensive construction operations eliminated. Approximate quantities for rock excavation could also be estimated. It would be uneconomical to explore long lengths of road line for that purpose by borings.

During a site investigation carried out on the Lune Valley section of a proposed motorway in Westmorland, difficulties had been encountered in boring and sampling in soil which contained a very high proportion of large rock fragments. For very shallow exploration it was found best, as the Author had suggested, to use trial pits, but for deeper exploration no such simple solution was found.

The rate of penetration was improved considerably by substituting diamond drilling for percussion boring, but it was a moot point whether or not it was cheaper—to the contractor anyway—because of the high cost of diamond bits. " Undisturbed " sampling in that type of material was virtually impossible, although some satisfactory cores had been obtained where the soil was free from large rock fragments. Tests on such cores, however, did not truly reflect the properties of the soil mass as a whole, even though the laboratory work on the samples gave a fair idea of the limiting values for the different properties for each main soil type. Nevertheless, it should be emphasized that whilst calculations based on such data were useful in the early stages of a project as a guide, the various design problems associated with all important structures and major earthworks should not be resolved without further detailed study of the soil conditions at each position individually.

The Author had mentioned that the preliminary soil survey might suggest that the horizontal alignment of a road should be altered to avoid areas of bad ground. Where re-alignment was out of the question, soil mechanics could offer considerable help in overcoming the engineering difficulties involved in carrying a major road over bad ground. Developments directed towards accelerating settlement and removing soft deposits provided the means for dealing with difficult conditions without changing the route.

Mention should also be made of the value of detailed geological surveys. For example, the characteristics of rocks in situ might exert considerable influence on the designs of cuttings and retaining walls. The information required in that connexion was not normally available from geological publications.

A secondary site investigation should include a study of any geotechnical processes that might be employed, and also a search for evaluation of potential constructional materials such as filling and concrete aggregates. It was encouraging to note that soil-survey drawings were included in the Author's list of contract drawings. Mr Wilson would go even further and recommend that all available soil and other data should be provided with the tender documents so that the contractor had the fullest possible knowledge of site conditions when he was considering his prices. That would undoubtedly lead to more intelligent tendering and keener prices.

In his comments on the treatment of slopes, the Author had mentioned a procedure for estimating the slopes for both embankments and cuttings. Whilst that might be acceptable in so far as it produced pleasing profiles, S should not be assigned an arbitrary value, but should be determined from the results of the soils investigation. Mr Wilson asked if there was any particular reason for the sharp edges being left to the shoulders of embankments and the toes of cuttings. His opinion was that curves at both those positions would be advantageous, especially on embankments where it

was extremely difficult satisfactorily to construct and preserve a sharp edge which would always be susceptible to weathering.

Finally, in view of the Author's reference to the C.B.R. method of pavement design, Mr Wilson asked whether, in fact, that method had been adopted and endorsed by the Ministry of Transport, for use on such schemes as the Lune Valley motorway.

Mr H. S. Andrew suggested that if the Author had in any way failed, it was perhaps in not starting with a definition of the aim and purpose of motorways. It was not known what sorts of traffic were being catered for, or at what speed it was intended to move the traffic from place to place.

Mr Andrew felt that a great deal of harm might be done to motorways when the time came to construct them if not enough boldness were shown in constructing a reasonable length of motorway connecting two big centres of traffic.

Personally, he would like to see a road constructed from London to Birmingham, or from the outskirts of London to the outskirts of Birmingham, the ideal being a road on which specially designed heavy goods vehicles with trailers could move with safety between the outskirts of the two cities at a speed which would enable the driver to take a train of vehicles there and back during an ordinary working day. The road conditions, the curves, and the gradients should be such that the driver would be able to move at a uniform speed, so that his average speed would approximate very closely to his normal cruising speed.

That was possible over country of that nature, but it would not be possible in the Lune Valley. Different standards would have to be adopted for different parts of Great Britain. If a road of that nature could be built and put into operation, the response of public opinion, of the transport industry, and of industry generally would be such that the remainder of the motorway problem would probably be solved without difficulty. If bits of motorways were built here and there the real benefits to be derived would be lost.

The Author had suggested that it might be necessary to open a motorway with a single carriageway of 22 feet. Mr Andrew appreciated that that might appear necessary under present conditions, but he believed that no greater dis-service could be done to the cause of motorways in Britain than by opening a road of that nature. He did not know any details of Mr Samuel's 40-foot cariageway turned into two 22-foot lanes, which was said to have caused an increase in accidents, but he felt that on a motorway with, presumably, no right-hand turning traffic, there could be no doubt that the twin carriageway would be safer than the other method. He was sorry to see that twin 22-foot lanes were the maximum that could be asked for, but he suggested that, if possible, land should be acquired and the lay-out on many sections of the roads prepared so that twin 30-foot lanes could be adopted. He was not suggesting that the volume

of traffic would immediately require twin 30-foot tracks from London to Birmingham, but the varying speeds of vehicles on the road might be such that those lanes would be required.

To return to the question of lay-bys, had they the right conception of a motorway? Was it a place where a man would be allowed to stop and admire the scenery? Previous speakers had mentioned acceleration and deceleration lanes at junctions, which were obviously necessary, and the Author had suggested, Britain being a small, densely-populated country, that the spacing of junctions would range from 5 miles to 1 mile. Surely any lay-by which was needed should be located somewhere where those lanes would enable him to get into it, and any stop between them should be a matter for police inquiry. It should only be an emergency stop which would permit a driver to pull-in on the hardstanding.

Mr Andrew said that he would like to see a hard shoulder on the central reservation. It would be far more useful there to the overtaking vehicle than it would be on the inner channel to the vehicle being overtaken.

Reference to land severance had been made by Colonel Bennett. The only hope was to find a motorway enthusiast with a good knowledge of agriculture. It was no good finding an agriculturist with a slight knowledge of motorways!

Colonel Sydney Green observed that it was stated in the Paper that motorways were expensive to construct and that full justification for them would be necessary. Traffic volumes, journey times, and safety were factors in that. In a Paper[19] published in 1937, the point had been made that a bird's-eye view of the traffic on the roads of Great Britain would reveal that the principal roads in country areas would be sparsely trafficked and in the great cities congestion would be observed.

From a recent Paper[20] on "Roads in Europe" it appeared that France had taken the same viewpoint, and their programme of motorways had started outwards from the great cities, as instanced by the rather lovely motorway to the west which started at St Cloud, near Paris, and did not go farther than 20 miles from the city.

In his "Preliminary Considerations," the Author had mentioned that the bulk of traffic moved between centres of population. It was known what he meant, but perhaps it could be more clearly expressed. In fact, the bulk of traffic moved within centres of population, and the distribution of the traffic converging on large cities was a very big problem indeed. The confluence of the roads in London as shown in *Fig. 1* was an example. There were twenty-nine principal roads at a 15-mile radius from the centre of London, of which the six shown in *Fig. 1* formed part. It was not generally known that about two-thirds of London's traffic was generated inside a 15-mile radius. At a 25-mile radius, only a quarter of the traffic

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[19] S. Green and A. C. Kain, "The Flow and Distribution of Traffic along Highways." *Surveyor*, vol. 92, p. 35 (9 July, 1937).

[20] M. de Bussy, "Roads in Europe." Instn Highway Engrs, 1953.

came from outside. The whole point was that the sting of a journey was often in the tail. One could travel by plane from Paris to London in an hour and a half, only to be faced with a 40-minute journey for the 13 miles from the airport to the heart of London—which included 2 minutes for negotiating the congested intersections at Hammersmith Broadway.

Traffic volumes on roads linking cities might range from 2,000 vehicles per day to 16,000 vehicles per day, and it might well be that more striking economic justification could be shown, taking into consideration traffic volumes, journey time, and safety, for the improvement of, say, the last 10 miles of a road than for the whole of the 90 miles which preceded it.

It was stated in the Paper that a considerable volume of commercial vehicles could be expected on the motorways, so that the range of speeds might lie between 20 and 70 miles per hour. In those conditions, with that speed range and the consequent desire to overtake, he was sure the Author's safe capacity for the dual two-lane motorway (4,000 vehicles per hour) was much too high if reasonable speeds were to be achieved.

It was perhaps a good opportunity to mention the valuable Paper by Mr Wardrop on " Some Theroetical Aspects of Road Research,"[21] in which he had given a practical example from a study of east-bound traffic on Western Avenue, Middlesex. That traffic flow of 450 vehicles per hour had a speed range of 2 to 61 miles per hour, and the calculated density of desired overtakings was 1,090 per mile per hour. Since the number of desired overtakings increased as the square of the traffic flow, it was easy to see that with a traffic flow of 2,000 vehicles per hour (the Author's capacity for two lanes in the same direction) and allowing for a speed range of 20–70 miles per hour, the desired overtakings would be very high. The actual overtakings would, however, be low, and the two lanes would become a procession, taking on the speed of the vehicle in front.

On p. 719, the Author had mentioned a motorway with a single two-lane two-way carriageway. Colonel Green hoped that they would be spared that, because the safe capacity of a motorway with two 11-foot lanes, having regard to the mixed traffic and the incidence of overtaking, would be extremely limited.

With regard to lay-bys for drivers' meals and rest periods, he agreed with Mr Andrew. In view of the experience gained of the amenities which drivers desired for those purposes—and they were fairly extensive—Colonel Green felt that it would be preferable to make such arrangements off the motorway, perhaps near a convenient junction.

Mr R. E. Rolt Hammond said that he did not agree with the idea of very long straights of, say, 20 miles. He understood that in the United States it had been found that drivers were apt to go to sleep, or something of that sort, on long straights, and curves had been introduced to keep them awake.

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[21] Proc. Instn Civ. Engrs, Part II, vol. 1, p. 325 (June 1952).

Motor vehicles ranged from the very heavy road trains which were at present being developed to travel at 40–50 miles per hour to super sports cars which could travel at 100 miles per hour or more. In view of those possible speeds, Mr Rolt Hammond felt that the roads should be designed so that drivers could " go all out " and get from place to place quickly.

The Chairman said he was a great believer in motor-roads. He wished to underline what Mr Andrew had said. He hoped that no one would hurry into the making of the first motor-road until everything was so arranged that a result could be given which would make the public believe in motor-roads.

He was not at all sure that an important factor ought not to be a lower-speed limit. It would not do to have the motorways patronized by the dear old lady out for an hour's spin in the country. The roads were designed to get traffic moving and get it out of the way.

*** **Mr A. J. H. Clayton** observed that the Author had dealt on pp. 724 and 725 with the question of " design speed." As he had rightly pointed out, although cars were capable of speeds in excess of 100 miles per hour, the probability was that the most common speed would be between 45 and 50 miles per hour. That being so, it had to be considered whether a " design speed " could in fact be adopted, and if so, what the expression meant. If the road was designed to be ideal for vehicles travelling at 70 miles per hour, it might be unsuitable for the majority of vehicles. It seemed that the road should in fact be designed for a wide range of speeds, on the principle of " the greatest good to the greatest number." It was already the practice to use a degree of superelevation considerably less than that ideal for the " design speed," but transition curves were commonly made longer than really necessary. Would it not be more suitable to design the road to be as near as possible ideal for, say, 50 miles per hour and check the design for higher speeds to see that they were not positively unsafe ?

The Author, in reply, said that Mr Samuel had mentioned the leeway to be made up in the maintenance and improvement of existing roads. All highway authorities probably had schemes which they were anxious to complete and he fancied such schemes would come before any great start on the motorways.

On the question whether a wide single carriageway was better than dual carriageways, Mr Samuel and the Author had had many arguments and there was a good deal to be said for and against each system. The segregation of opposing streams of traffic had obvious advantages but might give rise to a different form of accident. For instance, a car overtaking in the second lane of a uni-directional carriageway had little space for manoeuvre if a vehicle in the first lane swerved to the right. A common cause of such movement was a cyclist on the near side, but in the case of motorways there

*** This contribution was submitted in writing upon the closure of the oral discussion.—Sec. I.C.E.

would not be any cyclists nor would there be any right-turning traffic, which was also a frequent cause of accidents.

Another point, when considering economy, was that a single carriageway required a horizontal sight distance of 1,200 feet, as against 650 feet on a dual-carriageway road.

On the whole, the Author re-affirmed his view that motorways should be constructed with dual carriageways but agreed that an investigation into the relative accident rates and carrying capacity of the various types of lay-out would be of great value.

Colonel Bennett had referred to the fact that land was always regarded as " the best agricultural land." The Author had also come across that phenomenon ; the exception was where an exchange of land was suggested —when the land offered never seemed to have any value at all. He had tried to put both sides of the agricultural land problem in order to get matters into their true perspective, and came to the general conclusion that motorways were necessary but had to be constructed with strict regard to economy in both money and the use of land.

Colonel Bennett and Mr Drake had questioned the value of rounding the slopes of cuttings and embankments. That was mainly an amenity feature and unless it was to be seen and did some real good there was no point in the extra expense. It had been mentioned on p. 731 that slopes could often be used for the grazing of cattle, with boundary stones as required along the slope.

Mr Lovell had asked about the five specifications which the Ministry of Transport had issued at one time. They had not been mentioned in the Paper because they were a general topic and not peculiar to motorways. One had a broken-stone type of foundation consisting of two $4\frac{1}{2}$-inch layers of broken stone with a regulating course of 3 inches, making 12 inches altogether, plus " black top " surfacing. There were also the ordinary pitched foundation, concrete—both reinforced and not reinforced, and a stabilized-soil foundation. All had " black top " surfacing except the reinforced-concrete specification and the thickness of the foundation was related to the C.B.R. value of the formation. The broken-stone type was thought most likely to be suitable in the Lune Valley.

The Author agreed with Mr Drake that the choice of the first lengths of motorway was of the very greatest importance. Being a Lancastrian, he appreciated Mr Drake's point about the conditions in Preston and Lancaster. Both were towns taking a great deal of through traffic and they were also the focal points for several very attractive seaside resorts.

It had been suggested that flowing alignments need not, perhaps, be followed all the time, but he believed that it was worth while trying to co-ordinate the horizontal and vertical curves. It need not be carried quite so far as had been suggested in the past, certainly not to the point of making the construction very much more expensive, but subject to that it was something well worth doing. Mr Drake had shown some attractive pictures

of his model, and the model displayed in the Lecture Theatre had been constructed in a similar way. Although the idea was the same, Mr Drake's model was a bigger and better one, since he probably knew how to get money out of the Ministry better than the Author.

Mr Cardell had mentioned the value of contours, and the Author heartily agreed with him. It was true that lay-bys in the lowest positions might be on bad ground in some cases but not always, for one would seek to avoid the bad ground. He agreed that a better view was generally obtainable from high ground, and he had given that as one of the factors leading to the choice of a suitable site.

The question of widening the hard shoulders so that a vehicle could draw right off the carriageway had been mentioned also by Mr Lovell. They were not intended primarily as a substitute for lay-bys, although they could be used by a vehicle to draw partially clear of the carriageways in an emergency. Perhaps the most useful attribute of the hard shoulders was the confidence they would give drivers to keep in to the near side without fear of hitting a soft patch as the result of a slight error. For other than emergency stops, either Mr Andrew had the right idea when he suggested they should not be allowed on the motorway at all or they should be constructed at the carefully chosen sites of lay-bys. The latter would have adequate width, foundations strong enough for heavy standing loads and properly designed entrances and exits.

With reference to the remarks by Mr Wilson, the soil found in the Lune Valley was heavy boulder clay with many large stones, so that hand auguring was not very practical. He agreed with Mr Wilson about the usefulness of geophysical surveys for road location work and also with his suggestion that the fullest possible information on soil data should be made available to contractors tendering for a job.

Mr Wilson had asked why the edges on the shoulders of embankments and the toes of cuttings were not rounded. In practice they would not be so sharp as shown on the drawings but any pronounced and deliberate rounding as advocated for the tops of cuttings and the toes of embankments would reduce the effective width of the side verges. The Ministry of Transport had endorsed the California-Bearing-Ratio method of design and had adopted it for the design of motorways.

Mr Andrew had asked for a definition of the aim and purpose of motorways, the sort of traffic to be catered for, and the speed at which it would move from place to place. The object of the proposed system was to facilitate the flow of traffic between the main centres of population with greater safety and at a reasonable speed.

Under the Special Roads Act, the type of traffic which might use a special road—and it need not necessarily be a motorway—could be defined. In the case of motorways, the Author was of the opinion that all forms of motor traffic, including the heavier commercial vehicles, would have to be catered for if the roads were to develop their full economic value. Although

the design speed recommended was 70 miles per hour, that did not mean that all traffic would travel at that speed. It was intended that the bulk of traffic should travel at perhaps 40 miles per hour, keeping up a good even flow at around that speed. This was very much in line with Mr Andrew's views.

Mr Andrew had said he was sorry that twin 22-foot lanes were the maximum to be allowed. But that was not quite what the Author had said and he agreed there would be a few cases in which dual 30-foot lanes might be required. The capacity of the dual two-lane carriageways designed to free-flow principles would be very high indeed. For an ordinary all-purpose road the Ministry of Transport's Memorandum 653 gave the capacity of a dual two-lane carriageway as 15,000 vehicles per day or 1,500 per hour, and it was clear that with restriction of access, no standing vehicles, and no right-turning traffic, the figure would be very much higher than that. There were not many roads except in the big cities (which were outside the scope of the Paper) taking traffic of that volume.

Colonel Green had mentioned the traffic around London. The Author had looked up the average traffic on trunk roads within 25 miles of London, excluding the Metropolitan area, and found it to be about 10,000 vehicles per day. On the trunk roads of Britain generally, in the open country and again excluding the big towns, the average volume of traffic was about 5,000 vehicles per day. If one allowed for the attraction of a motorway and made generous allowance for a future increase of traffic, it seemed very probable that dual two-lane carriageways would provide ample capacity for many miles of the proposed motorway system.

Colonel Green had also drawn attention to the concentration of traffic within the big cities, especially London, and posed the interesting question whether or not it would be better to construct short but expensive roads to speed the flow of that traffic before embarking upon longer lengths between the towns. The Paper dealt essentially with the design of new motorways in more or less open country and was not intended to cover internal traffic problems, where so much depended on local factors other than the basic design of a highway.

With regard to the capacity of the traffic lanes, a maximum of about 2,000 vehicles per hour per lane had been accommodated under the conditions mentioned in the Paper. To allow for a higher percentage of slower vehicles, the Author had reduced that by half and was of the opinion that 1,000 vehicles per hour was a reasonable figure. Such volumes were not likely to be encountered on the majority of motorways, except at peak periods, when the faster drivers would have to conform more closely to the average speed.

Mr Rolt Hammond was against the very long straights advocated by Colonel Bennett. It was true they tended to monotony, but the number to be found in Great Britian would be so small that any good opportunity

should be taken. There was something quite exhilarating about being able to open the throttle with safety once in a while.

The Author agreed with Mr Clayton that the most common speed might be between 45 and 50 miles per hour. If anything, he thought the average might be a little lower, but he did not agree that the road would be any less suitable for vehicles travelling at that speed. As Mr Clayton realized, the superelevation was near the ideal at such speeds, since very little frictional force between the tires and the road surface was required to build up the necessary centripetal force. It would be misleading, however, to say the road was designed for that speed when, in fact, with modern surfacing it would be perfectly safe for very much higher speeds.

Correspondence

Mr J. J. Leeming commented on the Author's statement in connexion with transition curves, that experiments had shown that "a value of 2 feet per second^3 for C [the rate of change of radial acceleration] does not cause any great discomfort to driver or passenger in a car." Mr Leeming stated that, so far as he knew, his experiments were the only ones ever carried out on curvature and comfort, and, as a description of them, that was hardly adequate. The experiments had shown that very much higher values of the rate of change of lateral acceleration Q did not cause any discomfort at all. It did appear that within the practical range, Q had no effect on comfort whatever. C was a purely theoretical quantity, without meaning for practical purposes, and should be abandoned, since it merely added complication.

The function of a transition was to enable superelevation to be brought on, and to improve the appearance of a curve. Its length was a matter of small importance provided it was neither too short nor too long. The combined length of the two transitions should never much exceed three-quarters of the length of the curve under any circumstances. The effect of doing so was merely to sharpen the curve without reducing the value of C to any material extent. The lengths given in Table 1 of the Paper for the sharper curves were unnecessarily long—the inevitable result if any fixed value of C was used. There was little object in having transitions much longer than about 300 feet, and they should not be shorter than 100 feet with the minimum superelevation gradient of 1 in 100. If there was no superelevation a transition was unnecessary, unless for the sake of appearance.

Mr Leeming concluded that in treating the slopes of cuttings, it might be a better rule to make variable slopes where possible. Any bank of constant slope produced a hard line and looked conspicuous, whereas a variable slope blended more happily into the landscape.

The Author, in reply, regretted that it had not been possible to make

more than the brief mention of the test and in reference 10, p. 737, to the interesting experiments carried out by Mr Leeming. There had always been difficulty in assigning a suitable value to C, which depended on what was considered comfortable or safe for the driver, and as a result of his practical experiments, Mr Leeming claimed that it had no effect. His approach to the problem indicated that the lengths of transition given in Table 1 were unnecessarily long, at any rate for the sharper curves.

The Author agreed that the precise length was not critical but, taking the case of a curve which required maximum superelevation across the full width of the two carriageways, the lift of the outer channel would be about 5 feet. If that were applied at the rate of 1 in 100, the length required was 500 feet, compared with 478 feet recommended in Table 1 for a curve of 1,500 feet radius. In Road Paper No. 27, W. H. Spencer had stated that German practice was to develop superelevation at a gradient not greater than 1 in 200. That would mean doubling the length of transition and the Author would certainly regard that as unnecessarily long.

The slopes of cuttings recommended on p. 731 provided for variable slopes related to the nature of the soil and to the depth of the cutting. That would probably meet Mr Leeming's point.

Correspondence on the foregoing Paper is now closed and no further contributions will be accepted.—Sec. I.C.E.

RAILWAY ENGINEERING DIVISION MEETING

5 May, 1953

Mr J. C. L. Train, Member, Chairman of the Division, in the Chair

The following Paper was presented for discussion and, on the motion of the Chairman, the thanks of the Division were accorded to the Author.

Railway Paper No. 50

"The Design and Equipment of Modern Marshalling Yards"

by

Ralph Ernest Sadler, A.M.I.C.E.

SYNOPSIS

The Paper describes, in detail, the lay-out of a modern marshalling yard and explains two types of railbrake, or retarder, commonly in use. In an Appendix are given the essential formulae required for the purposes of designing a gravity yard and a series of curves is also given, the use of which, if reproduced on a sufficiently large scale, will still further simplify and expedite the working out of a series of examples.

As an antidote to the incidence of wasteful "pushing down," now so prevalent in many marshalling yards, a suggested design embodying a higher hump, together with secondary retarders, is put forward and a special example of a severe humping condition is shown to be achieved without the aid of shunters (known as "chasers").

The economies to be obtained by adopting these ideas in a large yard are claimed to be considerable, though difficult to assess, on account of consequential improvements upon the railway system over a large area and the possible closing of other yards thereby rendered unnecessary. In one scheme under consideration, an estimated net saving of £250,000 per annum is recorded, where one large modern mechanized yard is proposed as a substitute for a conglomeration of small yards on the same site and others in the vicinity.

A series of wagon frictions is suggested as the result of special tests at Whitemoor Up yard in 1952.

The Paper does not cover the details of signalling nor does it deal with the design of hump propelling-locomotives.

Introduction

It is now almost exactly 15 years since J. C. Kubale presented his classic Paper, "Gravitation Yards," before the Institution of Railway Signal Engineers.[1]

During these years a number of mechanized marshalling yards have been installed in Europe and recent investigations in Great Britain have shown that substantial annual monetary savings can be achieved by modernizing certain of the larger existing lay-outs.

[1] The references are given on p. 776.

In one case under investigation, on which the Author was engaged recently, the costs appeared to be capable of reduction by about £250,000 a year, after allowing for maintenance, renewal, and interest on capital, the average number of wagons passing through the yard in question being four thousand daily. In another case, the closing of five small flat yards was considered for replacement by one two-way mechanized lay-out. The estimated annual savings on the same basis, but for two thousand wagons a day, was of the order of £70,000. There appears to be, therefore, plenty of scope for large improvements in Great Britain, provided the necessary capital is forthcoming.

The approaching abolition of the grease-box wagon is an important factor in marshalling-yard development, since the variable and sluggish running of such wagons has so far proved one of the greatest problems of the hump designer.

Although this Paper contains the essential formulae required in the design of gravity marshalling yards, so many factors are dominant in the lay-out of a modern installation that the design is not simply a civil engineering matter and, for this reason, the Author is indebted to many friends for help and suggestions in presenting the Paper. He has drawn upon the Paper presented by Messrs J. I. Campbell and J. W. Watkins[2] at the Rome Congress of the I.R.C.A. in 1950.

In the past there has been a tendency to lay down sidings on spare land, or on land adjacent to junctions, without any serious attempt being made to assess the cost of the delay involved in moving traffic from point to point by this means. Flat shunting was, and generally still is, universal throughout Great Britain, though small humps have been introduced in many of the larger yards. These have been frequently determined not by performance required, but by the limitations of the site and lay-out. The results obtained from such installations depend upon the skill of the locomotive drivers and shunters, who, in the course of time, learn to know the special peculiarities involved, and it must be admitted that in many cases the results are surprisingly good, though not economic in manpower.

The introduction of a hump is a step in the direction of obtaining continuous shunting of any train, having the prime mover operating in one direction only and, if wagons are properly attended to upon the gravity run, damage to merchandise, wagon buffing, and draw gear, by the constant reversals of direction and violent braking associated with flat shunting may be avoided.

An early attempt to improve shunting methods on a considerable scale, by the aid of gravity, was undertaken by the former London and North Western Railway in the gridiron lay-out at Edge Hill. This included a primitive arrangement of a chain, with hook, which was intended to arrest any run-away wagons, and an illustration may be found in Acworth's book.[3] At a later date, in 1931, the contour of the land at Mottram (former London and North Eastern Railway) presented an

opportunity to dispense with the shunting locomotive altogether for the main operations. The ladder-track lay-out, which at Edge Hill did not present the best solution for obtaining an early and positive clearance of every wagon in any sorting siding, was remedied in the later, but smaller, gravity yard at Mottram by adopting a " balloon " lay-out.

Yards employing the gravity principle, on a limited scale, exist at Colwick and Clipstone on the Eastern Region and are, up to a point, quite successful. Again, small yards requiring up to about twenty sorting sidings may be worked satisfactorily by ordinary pilot engines over low humps. The initial gradient is usually 1 in 30 and good examples may be found at New England ; Cambridge Yard—Temple Mills ; Norwood Yard—Whitemoor ; and Goodmayes.

These small yards, situated as one of a group of yards near a main junction, or as a staging point on a through route such as Dunford Bridge, Thirsk, Connington, and Berwick, are, in principle, becoming obsolete for two reasons. First, the heavier freight-trains, by virtue of the abolition of wagons with grease axle-boxes, by the gradual adoption of a continuous brake and, on account of more powerful engines, will soon travel very much greater distances between points of examination (and changes of crews) than is the case today. Secondly, a mechanized marshalling yard capable of handling several thousand wagons a day allows the traffic to be concentrated in a very much smaller number of yards. Dunford and Connington have, in fact, already been closed.

The next decade, therefore, offers an opportunity, as never before, to reduce the number of marshalling yards in Great Britain. If the number could be reduced by as much as one-third of the present number, benefits would accrue in quicker transits and financial savings, beyond the dreams of all but those few who have given this important matter special study.

The purpose of this Paper, however, is not to describe the smaller yards but a larger yard of typical design, dealing with two to four thousand wagons per day, which requires a more extensive lay-out and also special assistance in braking the wagons upon their journey from the hump down the gradients, under the force of gravity, into the sorting sidings.

The examples of such a yard fitted with retarders are limited in Great Britain, at present, to Toton Up and Down ; Hull Inwards and Whitemoor Up and Down. Whitemoor Up yard was the first example to be brought into use in Great Britain, in 1929, and German retarders of Frölich type were imported, after these had been observed in use at Hamm.

Briefly, the progress of traffic at a yard undergoes three distinct stages : (1) through a group of reception sidings, each of which would preferably be entered directly from the running line without reversal ; these sidings, after being gathered together to form one or two lines over a hump, continue forward down a gradient (through retarders if provided) to : (2) the sorting sidings and thereafter to : (3) the departure sidings which, like the reception sidings, should have direct connexion with the running lines.

The lay-out may be varied so as to incorporate two parallel sets of departure sidings, depending upon whether the single hump is expected to deal with one-way or two-way traffic. With the latter, great economy of track, equipment, and staff is effected and the lay-out should essentially be located between the running lines if conflicting movements on these lines are to be avoided.

The brief description of a yard lay-out, given above, is now set out in more detail.

The Reception Sidings

All sidings should be made of sufficient length to accommodate the longest train, together with allowance for locomotive, brake van, and 100 or 200 feet over-run. Some shorter lines may be provided in special cases where sufficient special traffic considerations permit; nevertheless, they should be avoided, since a wrong point-setting with a long train into a short siding would result in serious delays owing to the entrance remaining blocked. In conjunction with these reception lines, the number and length of which is governed by operating requirements, there should be considered: (*a*) the gradient approaching the hump; (*b*) the disposal of the train engine; and (*c*) the facilities for the humping locomotive. So far as (*a*) is concerned, the main length of the sidings should preferably be level, but a rising gradient up to 1 in 260 in the direction of movement could be allowed for the greater part of the length of the tracks. The immediate approach gradient to the hump should be at least 1 in 50, to facilitate uncoupling, continuing through the connexions at the trailing end of the reception lines. The extent of the 1-in-50 gradient should be of not less than five wagon-lengths, though usually more, and must, in any case, be of sufficient length to gain the requisite height of hump, after taking account of previous gradients.

For (*b*) it is usual to provide a facing connexion just in advance of the hump, from which a track leads to the motive-power depot. The insertion of this connexion on the approach to the hump is undesirable, in that it lengthens the distance between the clearance points at the trailing ends of the reception lines and the apex of the hump. On the other hand, the location of the loco. release line on the approach to the hump enables the vertical radius of the crown to be maintained at a sharper flexure than otherwise would be the case, and this is beneficial in securing an early and positive start to the gravity run.

A vertical hump curve of 8 chains is satisfactory for humping and will pass short-wheel-base engines without damage. Consolidation class 2–8–0 locos are used in some cases over the humps at Whitemoor, but their axle boxes are fitted with a suitable amount of play in the horns especially for that purpose, otherwise damage would result, including cracking of frames.

In the case of the loco. release line being located beyond the hump,

then main-line engines must traverse the hump on every occasion and a vertical curve of from 10 to 11 chains is essential. This flattening of the vertical curve has the effect of delaying the start of the wagon away from the humping train, and this is a point which must be watched with care, otherwise unsatisfactory spacing of wagons may easily result.

An alternative arrangement, using two short curves with a level crest, is probably the best solution.

The facilities for the humping engines (*c*) are based upon the assumption that these engines should work only to and fro between the reception inlet and the hump and, in returning to propel another train, should be kept clear, so far as possible, of other trains, both incoming and those being humped. One or two humping engines are generally in use at any one time. In addition, therefore, to the reception sidings, a parallel-return humping-loco. line is required as well, with reversing neck at the inlet end. In order to effect a clear run-back of the humper, without reference to the signalman at the inlet end, this return humping line may be located in the centre of the reception group, with a dual inlet for incoming trains round each side of the reversing neck. (See Figs 1, Plate 1.)

Other versions of this arrangement are sometimes used, depending upon the special conditions of a particular site. If the loco. release line is situated on the approach to the hump, the humper must reverse into the general direction of traffic to gain clearance into the special return line just referred to. This arrangement precludes a close follow-up of the next train due for humping, unless, of course, a special humper release line is located beyond the hump. The lengthening of the lay-out between the gathering point of the reception sidings and the hump, referred to earlier in the Paper, is mentioned again, to show that there are two disadvantages with this lay-out which must be set off against the advantage of a sharper vertical curve in the hump.

If the loco. release line is located beyond the hump, then a similar line may also be used to clear the humper and permit a following train to be humped with a clearance as short as, say, 100 feet. If the humper is released in this manner, it cannot conveniently return upon a centre line in the reception group, and in such cases a line on the outside of the group would have to be allocated instead, but this arrangement necessitates some alterations at the inlet end. (See Figs 1, Plate 1.)

It is usual to signal the trains into the reception group from the running lines by an ordinary signal box ; thereafter movements are controlled into the motive-power depot and sorting sidings by a yard controller in a cabin at, or near, the hump. The movements of the special humping locos are controlled, in actual humping, either by coloured light signals, located at intervals along the reception lines and visible both ways, as at Toton ; by a three-position semaphore at the hump, as at Whitemoor ; by wireless directions in the spoken word ; or, as lately suggested, by coded track circuits actuating an indicator in the cab of the humper. A signal, or

signals, indicating "stop," "normal humping speed," and "slower humping speed" are required as the minimum.

The spoken word by wireless telephony is most effective and much time is saved, though there is a body of opinion which insists that transitory verbal instructions should be reinforced by persisting visual signals; nevertheless, a number of French yards, including Toulouse, have no visual signals. Wireless telephony proved most effective during wagon-friction tests which were carried out at Whitemoor Up yard in February 1952, since although load-changing and wagon-collecting were being undertaken at some distance and out of sight, they were kept strictly in step with the programmed tests being carried on simultaneously at the hump. Non-routine work may, therefore, be undertaken by this system without difficulty.

The Hump and Retarders

Before proceeding to give some details of the sorting sidings, descriptive remarks about the hump and retarders should be inserted here, in order to preserve the correct sequence of movement through the yard.

The vertical radius of the hump has already been mentioned. On and immediately following this, the gravity run of the wagon commences and an initial steep gradient is required so as to ensure a separation between wagons, which will enable them to be dealt with safely on their journey to the sorting sidings.

In Great Britain a humping speed of about 2·5 feet per second is the maximum which can be dealt with satisfactorily with lay-outs as they now exist, but in isolated cases a slightly higher speed appears to prevail. A speed of 2·5 feet per second is equivalent to the release of a wagon every 8 seconds, as an average. Mr Kubale, in his Paper,[1] mentions a humping speed of 4 feet per second, but the Author is unaware of any speed so high as this, which envisages humping a train of 60 average wagons in only five minutes. Although a speed slightly lower than 2·5 feet per second is generally in use at Whitemoor, this speed has been obtained there and was used in the consideration of designs for proposed mechanized yards at Ripple Lane, Temple Mills, and Colwick Up. This speed of 2·5 feet per second gives 9 minutes, net, for humping a 60-wagon train and, after allowing 6 minutes for a single humper to run round, permits four 60-wagon trains to be humped per hour. With two humpers operating within a well designed lay-out, from five to six 60-wagon trains may be dealt with in the same space of time or alternatively seven 50-wagon trains composed of the new standard 16-ton type. In one 8-hour shift, therefore, about 2,800 wagons could be dealt with as the maximum, though this figure would, in practice, probably be not more than approximately 2,400, assuming

that incoming trains arrived in sufficient numbers and at suitable spacing, and after taking account of change of shift, meal-time, releasing train engines, and a certain amount of " pushing down."

It will be seen that while the humping train moves forward at a very slow speed, the wagons are allowed to run forward on a steep gradient, either singly or in small groups according to the cuts made on account of ultimate destination.

The satisfactory initial separation gradient for the general run of wagons in use in Great Britain is about 1 in 18, though 1 in 17 is preferable if there is a preponderance of empty wagons, and this gradient usually terminates at the King points, that is to say, the first turnout into the sorting sidings. This is followed by lesser gradients, which, omitting any influence of retarders, should allow the worst-running wagon, in the worst weather, to run beyond the clearance point in the sorting sidings. For a typical series of such gradients see Figs 1, Plate 1. In any case, the overall gradient between the hump and farthest clearance point must not be so flat as to prevent the wagon having the greatest degree of friction from running with a slight acceleration upon this hypothetical line.

The sequence of turnouts, or switches, into the sorting sidings, is usually designated King, Queen, Jack (and sometimes 10), followed by the final turnouts or tandems into the actual sidings. It is important to secure as even a spread of curvature into the various sidings as possible, in order that the total loss of energy shall be equalized to the greatest extent. This can be corrected, if necessary, by forming a cross-camber in the formation of the sidings, those having the greatest curvature at entry being at the lower level, that is, the outermost sidings of the group.

Whilst it is important to bring the clearance point in the sidings as near to the hump as possible, and many authorities tend to overstress this, it is equally important not to spoil the possiblities of a good lay-out which will give sufficient lengths of initial steep gradient to permit (*a*) adequate spacing, by attaining suitable high speeds early in the run ; and (*b*) sufficient run (and time) to enable the retarder operator to appraise the situation he has to deal with. Furthermore, a short distance to clearance point may imply sharp flexure curves, which are undesirable.

The overall increased time incurred in shunting over a longer lay-out is, in any case, very small and certainly of no consequence, being the additional time taken by the last humped wagon in any train to cover the additional length of lay-out to the clearance point. Since there is a slight gap between the humping of trains, this point will be readily appreciated. The output of a yard is, of course, governed by the speed of humping coupled with the achievement of correct sorting.

It cannot be overlooked that in Great Britain the incidence of " pushing down " is only too prevalent. " Pushing down " means the using of a locomotive to close up the wagons in the sorting sidings to permit more humping to proceed. The bunching of wagons at the inlet end naturally

precludes further humping without allowing violent collisions of wagons in an effort to rectify the position, but cessation of humping usually follows quickly as the fouling points of adjacent sidings become involved. In some modern yards, pushing down is recorded as taking as much as one-third of total shift time.

The cost of " pushing down " will readily be appreciated, but will not so easily be assessed, for whole trains will be blocked back on running lines and loops away from the yard site. Pushing down forty sidings would take about 2 hours, so that the implications in closing down a large yard for so long a time, possibly several times a day, is a very serious matter indeed. Not every siding, however, requires to be dealt with at any one time, but nevertheless this is undoubtedly the most unsatisfactory feature of hump yards at the present time.

The Author's contention is that this trouble can be rectified, and rectified economically, by adopting a policy which includes the provision of a higher hump, allowing for higher initial gravity speeds giving improved wagon spacing, and also by installing primary and secondary retarders instead of providing one set only. The solution differs in each example according to the special circumstances, and it is merely a question of applying a series of calculations and drawing out graphs in relation to a selection of gradients, until the best arrangement becomes apparent. The cost of providing secondary retarders is shown elsewhere in the Paper to be less than the capitalized cost of " runners," who would be provided in any case according to present practice. The only additional capital cost, apart from the retarders, is, therefore, the earthwork in the higher hump, a longer length of single track before the King points and, possibly, a small amount of extra land. At present there are, surprisingly, no secondary retarders in Europe, but in America secondary and even tertiary retarders are common.

Retarders are controlled from an adjacent tower and typical examples of two types of brake and one control tower are shown in *Figs 2*, *4*, and *6*, and in Fig. 3, Plate 1. The operator obtains an elevated and " plunging " view of the wagons. With a primary retarder only, an operator has no opportunity of correcting a mistake and naturally even the most experienced man cannot avoid such an occurrence sometimes, since the difference in running between good or bad, or empty and loaded, wagons is quite appreciable. Open wagons readily reveal their state of loading, covered ones do not.

In the latest preliminary designs of yards prepared on the Eastern Region, incorporating mechanical secondary retardation, the minimum time interval of 13 seconds is given, relating to a fast-running wagon, between the time of leaving the primary retarder and entry into the secondary. The same operator is intended to manipulate both brakes, so that, in any instance of maladjustment, he has a good chance of setting matters right. The degree of retardation is variable at the will of the

Fig. 2

Control Tower and Hydraulic Retarders at Whitemoor Up Yard

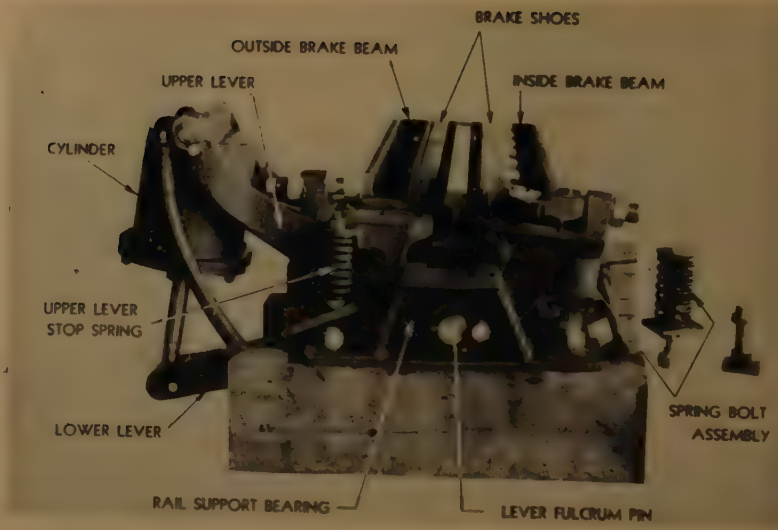
Fig. 4

Electro-Pneumatic Retarder at Saint-Germain au Mont d'Or

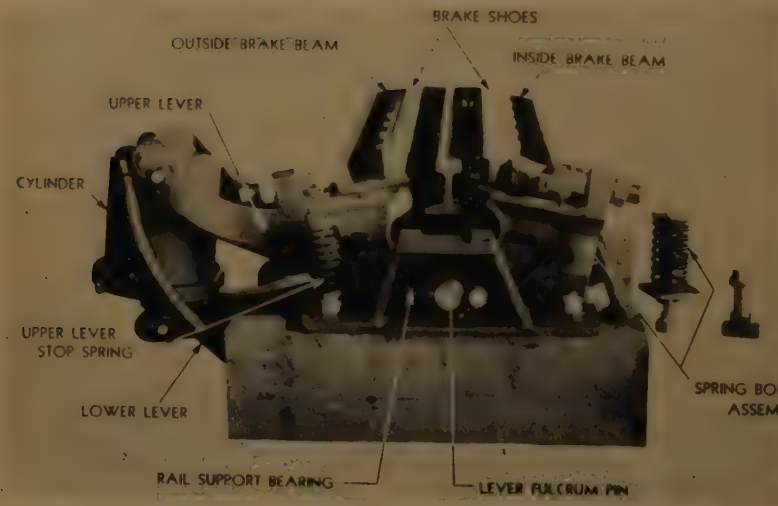
Fig. 5

Point-Control Panel and (right) Route Selector at Whitemoor Down Yard

Figs 6



IN RETARDING POSITION



IN OPEN POSITION

CROSS-SECTIONS OF ELECTRO-PNEUMATIC RETARDER

operator, quite apart from the length of the brake shoes, and in one pattern different pressures may be applied over each half of a full-length retarder, whereas in another make the weight of the vehicle being retarded is a factor of the braking applied.

In Great Britain a length of primary retarder of about 69 feet will suffice, and a length of 29 feet is suggested for the secondary. It is advantageous to have sufficient brake power in the primary to stop a wagon altogether, in case of a mishap to the preceding one farther down the grade. The makers of the brakes are able to provide a retardation up to the order of 5,500 foot-lb. per axle per foot run of brake. This figure, however, is rather less in the case of close-spaced bogie wheels. On the Eastern Region 75 per cent of the retardation figure is used in such cases.

The secondary retarders, having regard to the economics of numbers, are placed as near as possible to the clearance points, whereas the most suitable position for the primary is between the King and Queen switches. There are, therefore, on this basis, two primary retarders. Eight secondary equipments, each serving 6 or 7 sidings, are included in the latest schemes prepared on the Eastern Region.

It is helpful to provide a self-accelerating gradient through the retarder, so as to ensure restarting in case of accidental stoppage through over-braking. This arrangement, however, is only a palliative since speeds thereafter would be slow. Nevertheless, clearing the track as just described is preferable to a possible shut-down or serious collision, especially within the brakes.

The maximum speed likely to be obtained in the course of a run down from the hump is about 26 feet per second, or 18 miles per hour, after running down a slope on 1 in 18 as indicated in Figs 1, Plate 1.

In some countries, including France, where at present only primary retarders are in use, there is a school of thought which prefers to dissipate all the vertical drop available for the gravity run by the time the exit from the retarder has been reached. The basis of this arrangement is that the wagons run through the critical connexions, immediately following the retarders, at a higher speed and thus reduce the risk of collision by obtaining quicker clearance of the more important switches. The wagons are consequently running on the level, which is, of course, a decelerating " gradient."

This laudable plan can be quite effective if brakesmen are employed, with or without slippers, and if the retarders are placed relatively near to the clearance points, which infers the use of not more than six sidings to one retarder.

The Author does not recommend this flat lay-out for use with British rolling stock and was not very impressed by a demonstration given, during extremely cold weather, on the Continent, where each retarder served at least eight sidings. Following wagons frequently caught up with those preceding and a large proportion of mis-humping occurred. Nevertheless,

the somewhat better and more constant running qualities of French rolling stock, attributable in large measure to the high proportion of roller bearings and greater loads carried per axle, does produce quite good results in reasonably good weather, as the Author has witnessed at Villeneuve and Achères.

At Villeneuve there are, however, six retarders to serve forty-eight sidings and Achères has five to cover only thirty-one sidings, though there are also eight making-up lines into which wagons may be humped. Each yard has only one operator for retarders.

The latter installation, particularly, has the brake equipments so placed that they are virtually in positions which would be allocated to secondary retarders in a larger lay-out. The fact that, in average weather, collisions above the Achères retarders rarely occur, verifies the constant running qualities of the French stock, which is an essential feature if only one set of retarders are used which are placed well down the gradient.

There are several methods of dealing with point operation for the gravity runs into the sorting sidings. In the early lay-out at Whitemoor, a cut list is made by a shunter as he walks down a newly arrived train standing in the reception sidings. This list is sent from the hump cabin to the control tower through a pneumatic tube. The cut list contains not only the number of wagons in each uncoupled group, but also the siding number into which they are to be placed. The point operator in the control tower sets up a magazine of automatic movements of the King, Queen, and other leading switches which are actuated by point motors. These switches are set in motion and operated in sequence by the wagons themselves through a series of short track-circuits. The final sets of switches are set by hand through switches on a special diagram panel. (See *Fig. 5.*)

In order that the automatic sequence of switch settings shall be effective, the minimum spacing between wagons must be observed, or exceeded. At Whitemoor this minimum is 15 yards, which gives 19-yard centres between single open-type coal wagons and the like, and 21 yards between centres of two-axle tube wagons of long wheelbase. Single cuts, that is to say, single wagons of short wheelbase, following in sequence, provide the limiting factors in respect of track circuits. Long wagons or groups of wagons always give good gaps between cuts.

Point-setting at Toton Up yard (Midland Region) is of much later design and is completely automatic, being controlled from the hump cabin by an operator, who observes chalked siding numbers upon the nearside ends of wagons approaching the hump. In case of emergency, however, individual points may be worked from the control tower. A very full description of the arrangements for routing the wagons down the hump at Toton Up yard appeared in issues of the "Railway Gazette" during November–December, 1951.

In France there is an ingenious point-setting machine, operated by track circuits, in which each group of wagons is represented by a metal

ball falling through a series of contacts. The descent of the individual balls is regulated by the descending wagons operating the track circuits and a mis-hump expels the appropriate ball from its usual course through the machine and thus gives an automatic indication of a situation requiring rectification. The ball does not indicate which wagon has run astray (though this may be verified by quick observation) since the ball only indicates which siding the wagon should have entered. The machine, like others mentioned previously, is too intricate to describe in a Paper of limited extent. A fuller description has been given elsewhere.[4]

At times, the hump shunter may influence the spacing of wagons rolling from the hump, by momentarily pinning down the handbrake of a good-running wagon which is known to be following a bad runner. The condition of the wagon next in rear naturally has to be considered, but regulation by this means, though strictly limited, is practised at Whitemoor and Toton with a considerable measure of success and must avoid a due proportion of mis-humps, which are expensive to rectify.

There are some wagons with wide tires which cannot be retarded on certain brakes and, in addition, the few remaining vehicles with Mansell wheels are precluded from being retarded at all, because the brake shoes shear off the projecting rivet heads associated with this otherwise excellent type of wheel. The last-mentioned wagons, special loads in special vehicles, and cattle in trucks are not humped in the ordinary way, but are conducted down the full length of the gradient by a brakesman, who regulates the speed throughout as may be required. At such times the hump " stop " signal is given as soon as the special wagon is away from the hump on its own and the brake of the next wagon is temporarily pinned down to hold back the rest of the humping train. It is upon occasions such as this that wireless communication with the driver is of such value.

Retarders or Railbrakes

There are now two main types of retarder in use in Europe :

(*a*) the hydraulic Frölich pattern manufactured and supplied in Great Britain by Metropolitan Vickers, G.R.S., Ltd, and

(*b*) the electro-pneumatic type manufactured by the Westinghouse Brake and Signal Co., Ltd, in France.

A third type, the eddy-current pattern, also by Westinghouse, was in use at Whitemoor Down yard for 17 years.

This last type, as used at Whitemoor Down yard, possessed certain disadvantages, such as breakdown of windings, owing to the electric magnets being located beneath the rails ; and high current-costs arose from the fact that the mercury-arc rectifiers were left on circuit most of the time. The Author is of the opinion that a re-design of the electro-magnets would have been possible, which would have allowed them to be

placed clear of surface water, which inevitably worked its way into the pits during bad weather. Difficulty was experienced, at times, in striking the mercury arcs, which caused delays to traffic. They were, therefore, as mentioned above, left in circuit for the greater part of the time the yard was open. No doubt this defect would be rectified in the new design. It is not believed that any retarders of this design are now obtainable in Europe.

There is a fourth brake, the Saxby, of which some examples are in use on the Continent.

Hydraulic Retarders or Railbrakes

The hydraulic pattern of retarder is illustrated in *Fig. 2* and Fig. 3, Plate 1. This brake requires a pit underneath the track and Fig. 3 shows the braking rails in the operative (raised) and open (lowered) positions respectively. The braking rails rise to approximately 4½ inches above the top of the running rail when in the braking position. Oil is now used as the hydraulic medium, thereby improving the operation of the mechanical portion of the equipment and obviating the necessity of providing heaters in the pits to prevent freezing-up. This substitution for water was first tried out at Whitemoor Up yard. In the earlier installations of these retarders, weight-loaded accumulators were used. These necessitated somewhat expensive buildings, with towers to accommodate the travel of the ram. A recent development has seen the introduction of the compressed-air accumulator, requiring far less space and no special foundation or tower. The first installation of this type was at Whitemoor Down yard in 1950 and a similar arrangement has been provided at the new Up yard at Toton.

The railbrakes are operated from a central tower by a small lever for each brake and a fine degree of retardation can be achieved. As mentioned previously, the weight of the wagon automatically becomes a measure of the retardation provided, always accepting that the operator has raised the brake rails to the working position, when the " feel " of the wagon is reflected on the lever in the tower.

Maintenance is carried out from the pit and preselected periods are set aside each day for routine inspection and adjustment.

The whole length of the brake shoes is in one piece and, therefore, any application is operative uniformly throughout. The general lay-out of mechanism precludes the insertion of insulated joints within the retarder for track circuiting purposes, or siting on curved track.

At both the Whitemoor yards renewal of railbrakes has taken place in recent years. In the Up yard hydraulic was replaced by hydraulic and a new and separate hydraulic power house was provided as well, the original installation of the latter, in the basement of the control tower, being too cramped. In the Down yard eddy-current type was replaced by hydraulic.

These newer-pattern hydraulic brakes by Metropolitan Vickers, G.R.S., Ltd, are giving good service, but experience has shown that brakes requiring pits under the track cause considerable dislocation of traffic at renewal, particularly when alterations to the pits themselves may be necessary at the same time.

At Whitemoor Up yard, there being four brakes, only 25 per cent of the yard was put out of action at one time, but in the Down yard at the same place 50 per cent was rendered unusable, since only two brakes were installed there. It is, therefore, advisable with retarders, and particularly with any pattern requiring a pit under the track, to consider the situation arising after the development of a serious defect, or at a renewal. On this score, four main brakes are preferable to two. At complete renewal, including pits, civil engineering work upon each pit at Whitemoor occupied at least one month and after this the Mechanical and Electrical Engineer's department was engaged for a similar time.

Electro-Pneumatic Retarders or Railbrakes

The electro-pneumatic type of retarder is illustrated in *Figs 4* and *6*. This is known as the " nutcracker " type and the weight of the wagon to be retarded is not an automatic factor of the retardation ; the operator, therefore, has not the same " feel " as in the case of the hydraulic retarder.

The composition of the brake is a development of the well-known Westinghouse air brake, used on rolling stock, and the cylinders will be recognized at once. Pits underneath the tracks are not required for these brakes, they are simply set down upon 10-inch-by-10-inch timbers, laid on a firm bed of hardcore.

Since there is no metal connexion between the equipment attached to each rail, insulated joints for track circuits are permissible within the brake. In addition, the brake may be laid in curved track and it is sometimes provided upon one rail only, thus making possible installation within the confines of a turnout, and opposite to a crossing, if saving of space is an over-ruling consideration. Owing to the flexibility of the brake shoes, effective braking can be maintained upon a rocking vehicle and upon vehicles with different widths of tires.

Fig. 4 shows the general arrangement. Brake shoes are in unit lengths of 6 feet 3 inches with flexible joints between them. There are special run-on and run-off sections which are each 7 feet 9 inches long and re-railers are provided. These brakes, unlike the hydraulic pattern, have not quite the fine degree of retardation, there being usually four steps of pressure. In the case of the installation at Le Bourget Impair, Paris, these pressures are 30, 60, 90, and 120 lb. per square inch.

Major brakes are usually operated in two parts, so that a workable degree of variation in retardation can be achieved quite easily ; in fact, one part need not be energized at all, thus giving a total of fourteen degrees of retardation in one brake.

Short secondary retarders of this pattern would, of course only be installed in one part, so far as pressures are concerned.

In operation, the hydraulic retarder is not particularly spectacular, but the brake cylinders of the electro-pneumatic type present a peculiar see-saw appearance on the passing of a wagon.

Air is compressed in a power-house suitably located near the control tower, and vee-belt-driven two-stage compressors, with intermediate coolers, are usually provided. Storage cylinders are placed in pits at the sides of the tracks and these serve the dual purpose of ensuring coolness of the air and providing a low point for collection of condensate. The valves adjacent to the cylinders are electrically controlled, so that the time-lag of pneumatic operation, in response to a movement of the small operating lever on the panel in the control tower, is of no consequence.

If any section of the brake becomes out of order, this may be temporarily cut out without requiring the retarder to be taken out of service. General maintenence is carried out upon the same lines as with the hydraulic pattern, but above ground, and complete renewal can be effected in approximately 4 to 8 hours. This last circumstance is an especially important point if only one or two retarders are installed at the entrance to the sorting sidings.

No electro-pneumatic retarders are yet installed in Great Britain, but they are in general use in France and the United States of America.

Manual and Slipper Brakes

The final factor in braking, essential where primary retarders only are used, is the brakesman, who is generally termed a "runner" or "chaser." In Britain, where side-lever wagon-brakes can be applied instantly, the runners are provided with short lengths of timber specially shaped to facilitate the knocking-on of the brake and also for pinning down if required. Considerable skill and agility are required to catch every wagon and failures to effect the desired braking sometimes occur. Rail slippers at certain yards are used at the entrances to the sorting sidings and these are more positive in action. However, if these are once inserted, they cannot, in some cases, be removed until the wagon comes to rest. Overbraking cannot, therefore, be rectified, as in the case of applications of the hand brake, but some types of slipper brakes may be automatically applied and ejected.

Four runners are employed at each of the Whitemoor yards and about the same number were previously employed at Le Bourget Impair, where retarders are installed. At the present time the French National Railways are employing one brakesman to every three or four sorting sidings, which is very extravagant, in the Author's opinion. These numerous brakesmen completely arrest the progress of the wagons with slipper brakes, removing them immediately at rebound, and then shoulder the wagons into motion again to allow buffering up at about ½ mile an hour. This method naturally

dispenses with claims for damage to merchandise, but presents a startling anticlimax after taking note of the excellent mechanical installations in the area around the hump. The capitalized cost of so many brakesmen is in excess of the costs which could be attributed to a reasonable number of secondary retarders.

However, French practice is at present dictated by high policy and it is claimed that damage to wagons, originating in the yard, has been reduced to one wagon per thousand. In Britain the comparable figures are 2 to 6 wagons, per 1,000 humped, in a mechanical yard.

With the installation of secondary brakes, it is proposed to reduce the number of runners to one, the intention being that he would attend to special wagons only and be able to report conditions at the entrance to the sorting sidings as occasion demanded.

The savings effected, on the above basis, in the cost of chasers in a yard working a 6-day three-shift rota, should be about £3,000 per annum, to which should be added the savings in cost of repairing cripples generated in the yard. Assuming that a figure as high as 50 per cent in excess of that now recorded by the S.N.C.F. (Société Nationale des Chemins de fer Français) is achieved in Great Britain, using secondary brakes, that is to say, 1½ cripple per thousand wagons humped, and taking a yard dealing with an average of 3,000 wagons per day for 300 days per year, the savings in repairs will be about £6,500. This makes a total saving of £9,500 per annum, which is more than the amount of annual capital charges upon eight short secondary retarders. Further, the reduction in the number of cripples naturally gives a better service to the trader and will be worth something.

The maximum degree of retardation effected by a short brake on a single two-axle wagon would be in the region of 270,000 foot-lb. of energy absorbed. The application of a wagon brake, suitably pinned down, would not provide anything like this figure, having regard to an equal distance for application. In view of the certainty of application, the case for the secondary retarder is, in the Author's opinion, strong for the larger yards.

Twin Tracks at the Hump

One more point remains to be dealt with in the hump area, namely, whether one or two lines should be provided over the hump. In the latter case, a scissors crossover lay-out becomes necessary just beyond the hump.

The twin track over the hump is usually inserted to enable a second train to approach directly in the wake of another just completing disposal of its wagons into the sorting sidings. If, however, the train-engine-release line is located on the far side of the hump, having regard to the direction of travel, and the same, or an adjacent, connexion can be used for the disposal of the humping engine, then, as explained earlier in the Paper, a close follow-on is possible, with one hump track only. On the

other hand, a second hump line may be inserted to permit simultaneous humping into selected and non-conflicting sorting sidings. Unless the nature of the traffic specially requires, or permits, this latter arrangement, the Author does not feel that a second track is justified. Certainly the omission of the second track permits the suppression of an objectionable scissors crossing on a steep gradient, over which wagons run at all times under gravity and at a relatively high speed while they are momentarily running free.

The Sorting Sidings

The number of sorting sidings is dictated by the number of separate classifications which the Operating Superintendent requires to make. The maximum number which may be reasonably served from one hump on an average site is about 50. If occasion demanded, and a sufficient length of site could be made available, the Author sees no insuperable difficulty in providing for twice that number, but tertiary retarders would be required, although the average usage of each siding per day in the busiest yard would be only about fifty wagons, which is very low.

Up to the present time it would not appear that yards have been provided with one track for each and every destination, therefore secondary sorting, sometimes with a low hump, or special gradient, has been necessary. As labour costs increase, schemes embodying more primary sorting sidings become more attractive. Secondary sorting can be undertaken on a small dead-ended yard situated near the outlet of the sorting sidings (see Figs 1, Plate 1) or it may be carried out into the outlet end of the sorting group. Wagons may even be rehumped, provided traffic conditions permit this to be undertaken in the main yard, if partially cleared at fixed times for the purpose. Nevertheless, secondary sorting is expensive, not only in manpower, but in engine power, in delays to traffic, and in increased detentions of wagons.

Apart from sorting sidings having definite traffic destinations, there are also required some, or all, of the following :—

1. Cripple siding.
2. Brake-van siding.
   (*a*) Through siding, with small hump near outlet end for feeding brake-vans, after being serviced, on to trains drawn out into the departure sidings, which group, if provided, follows the sorting sidings. This siding is required for a one-way or two-way yard.
   (*b*) Short siding for a two-way-worked yard only (but in addition to (*a*)), having one group of sorting sidings with an outlet towards, and avoiding, the hump in the reverse direction to the general flow of traffic. This siding presents a peculiar difficulty and requires to be fitted with a buffer capable of

stopping a carelessly retarded brake-van at about 20 feet per second, for which a special long-stroke hydro-pneumatic buffer is suggested (see Fig. 7, Plate 1). The buffer has an abnormally low recoil value of approximately 1 foot per second at full compression, which is necessary, in conjunction with the design of gradient, to prevent rebound of the brake-van beyond the fouling point at the entrance to the siding.

3. Transfer siding.
   This is only necessary if two single-direction yards are provided.
4. Petrol sidings.
   Special attention to retardation is necessary but a tertiary retarder might be advisable on one or more sidings set apart for this traffic, assuming that secondary retarders operate upon all other lines.
5. Siding for wagons to wait order.

The length of the sorting sidings is governed by the length of trains usually worked to the destinations designated for each siding. The longest sidings in a balloon often occur at the centre of the group. These could be designated for empties traffic, since naturally such trains are longer than those composed of loaded wagons. It is important to make all these sidings about 25 per cent in excess of the train length at despatch, in order that humping may continue while a pilot engine is engaged in closing together and drawing out a completed train from the sorting sidings at the outlet end and into the departure group.

Where there is neither room nor special need for departure sidings, trains may depart directly from the sorting sidings to the running lines.

It is advisable to provide a slight rising gradient towards the outlet end of the sorting sidings, to assist in the prevention of over-run. They should, therefore, be "dished" longitudinally, by providing a falling gradient of about 1 in 200 to 250 continuing from a point near the entrance of the sidings for a sufficient distance to ensure shaking down of wagons as a whole, having regard to bad runners which may not have closed up with those already humped and standing well inside the sorting group.

Before proceeding to the description of the departure sidings, there is the question of transit cattle to be dealt with. A cattle dock with several pens and watering facilities should be provided in proximity to the outlet of the sorting sidings and also to the secondary sorting sidings already mentioned (see Figs 1, Plate 1).

The Departure Sidings

In order to save in overall length of the yard, it is convenient to collect all the sorting sidings into two parallel lines and continue these to form the two centre departure sidings, provided a scissors crossing between them is included on the way. Movements from any sorting siding into any

departure siding can thus be effected. The number of departure sidings is governed solely by traffic considerations. There are ten at Whitemoor Up yard but none in the Down yard at the same place. Toton has no separate group and four are planned in one design at Ripple Lane. This shows that there can be no general rule. Their number is governed by the number of train loads in the sorting sidings, at any one time, which have not an immediate path forward on the running lines. Train loads must, therefore, be moved from the sorting sidings to the departure lines, in order to avoid those particular sorting sidings becoming full and interfering with the progress of humping. If the yard is two-way working, up and down departure lines are laid in side by side and suitable outlet connexions provided in both directions. There should be included, in the lay-out, spurs for the pilot and train engines, so that these may be refuged clear of traffic lines when not required. Figs 1, Plate 1, show an arrangement of these spurs and also the provision of a departure line from the sorting sidings, which passes the side of the hump.

At the outlet of the yard the ordinary signalbox comes into operation again, the movements in the area between the sorting sidings and departure group being usually controlled by a pointsman located at a ground frame near the scissors crossing referred to above.

Train Engines

Train engines, after being released at the hump, should be able to pass directly to a depot. If a normal depot is not in existence, or to be provided, turning and watering facilities should be allowed for and, in addition, one or two engine ash-pits. A connexion from this depot is required round the yard as a whole, so that an engine released from traffic at the hump may, after being quickly serviced, present itself for the return load in the departure group, clear of marshalling operations. This may require a track under the hump.

Full Loads, Etc.

Apart from traffic passing through the yard for sorting purposes, it is often necessary to make provision for dealing with full loads for one destination, not requiring to be humped. Running loops, with connexions to appropriate positions into and out of the yard lay-out, are adequate for this purpose, provided engines may be changed with ease and odd wagons detached and attached as occasion demands.

American Yards

Little or no reference has been made in the Paper to American yards; it is felt that conditions there differ so much from those in Great Britain

that the available data would be of but limited use to a designer in Britain. The cars are much longer and considerably heavier. Thirty-one tons on two axles is the maximum in Britain in general service, though there are a few 35-ton two-axle wagons, whereas 90 tons on two 4-wheel bogies is common in the United States and 110-ton wagons with the same wheel arrangement are sometimes used in everyday traffic. It will be seen, therefore, that axle weights are generally about 50 per cent heavier than in Britain.

There are no grease-box journals in America, which is another factor favourable to good running ; further, it is common practice, in cold weather, to arrange for the insertion of hot oil in the axle boxes as the cars approach the hump. All this influences the circumstance of the inclusion of less severe initial gradients ; 1 in 25 is common as the main acceleration gradient and is apparently satisfactory.

In the Air Line yard at Milwaukee a tandem lead is inserted, together with one plain turnout, after the single primary retarder and before the four secondary ones. This is an unusual and non-symmetrical lay-out ; though tandems are included elsewhere with advantage in designs made in Britain, they are not usually placed above the retarders.

In passing, it should be recorded that at the Milwaukee yard the five retarders and point switches, from one double-track hump into twenty-five sorting sidings, are all worked by one man from switches on a single panel only. In saving of manpower this is a great advance over any previous design. There is also automatic speed-control actuated from about thirty short track-circuits located within the retarder. Descriptions of this yard have been given elsewhere. [5, 6]

Another feature of American yards is the provision for inspection beneath cars at hump approach. There is no similar example to be found in Britain.

Wagon Tests and Design Formulae

The formulae used in the design of a marshalling yard and given in Appendices 1, 2, and 3, are merely derived from well-known fundamental equations given in any text book of dynamics. The values of friction, however, have had to be obtained from tests and these were carried out at Whitemoor Up yard in February and July of 1952.

In the first test, cold weather and dry rails were required, but neither was obtained. Speeds of three wagons were recorded at various points down the hump gradient by assistants equipped with Smith-type surface tachometers. These instruments were modified for the test by fixing large-diameter wheels to avoid over-running. The tachometers were engaged with a horizontal shelf plank fitted to each wagon.

The results were quite successful, though disappointing in some respects.

(*a*) Unless the tachometer was applied to the centre only of each shelf for a very short space of time at position No. 1, just below the crown of the hump, very erratic results were obtained. This is quite understandable, since the wagon was undergoing a high degree of acceleration from an initial low humping speed at that time.

(*b*) Difficulty was experienced in holding the tachometers on the shelves at the highest speeds lower down the grade. This was much aggravated by the fine driving rain and undoubtedly some slip between the tachometer wheel and wagon shelf occurred on some runs. The periphery of the wheel was milled. A Dines anemometer was located near the hump during the tests.

In the second test, during July, the weather was quite good. Two 13-ton six-plank open wagons were altered so as to permit the hand-brake to be operated from within the wagon, in case of need. Platforms were provided over the leading end to carry a ciné camera at an upper level, and a stop watch and a Dines anemometer-dial at a lower level. The latter was fixed with the north-south axis in line with the wagon. The camera was pointing directly downwards and recorded, simultaneously, the dial of the stop watch, the dial of the anemometer, and targets previously fixed on the upper surface of the sleepers, in the 4-foot way, at changes in gradient and other selected positions, the distances between all of which had been carefully measured beforehand. Speed was obtained by noting the number of film frames per second as recorded by the image of the stop watch and relating this afterwards to the known distances between the targets. This method of obtaining the speed has proved very laborious on account of considerable variations in the speed of the camera. Unless a camera of very reliable and uniform speed can be obtained, it would be preferable to include the dial of an ordinary speedometer in the field of view. Shutter speed would not then be important and the camera would only be required to run while passing over target positions.

Upon each test date, a slow rolling test was made with a wagon passing down an easy gradient, and also full run tests from the summit of the hump into the sorting sidings having the maximum and minimum degree of curvature at entry. A measure of the retarding effect of curves has therefore been obtained.

The calculation of the passage of a wagon upon a vertical curve is somewhat involved, if carried out exactly. The simplified approximate method given in Appendix 2 has been carefully checked against the exact method and errors of speed at the termination of the curve are so small as to be of no consequence when using the method suggested here.

Wagons fitted with roller bearings are now being provided on the Continent and, if humped in sequence with certain types of oil boxes, are

likely to present difficulties in humping, but this contingency has not yet arisen in Britain. The introduction of roller-bearing wagons, running concurrently with those now in use, may well require the provision of a short checking retarder just clear of the vertical curve of the hump, in order to achieve wagon spacing which will allow the track circuits to operate the switches in the proper sequence. This arrangement is merely a natural development of the momentary pinning-down of a wagon-brake at the hump, as is now practised at Whitemoor and Toton.

Conclusions

The total length of the six single retarders at Villeneuve St. Georges, S.N.C.F., serving forty-eight sidings, is 450 feet.

In a design recently prepared on the Eastern Region, a total length of only 375 feet has been allowed for, in primary and secondary retarders, to serve the same number of sorting sidings.

However, since the wagons in France are somewhat heavier, this is not a fair comparison and, to bring the two cases into line, the total length of 375 feet would have to be increased to approximately the Villeneuve figure.

It will be seen that the provision of secondary retarders does not require an additional overall footage of brake. In fact, the length of brake which can be applied to any wagon on its journey into the sorting sidings at Villeneuve is 75 feet, whereas with the adjusted figure, incorporating primary and secondary equipments, no less than 99 feet of brake can be applied, if need be. This is an increase of more than 30 per cent. In the Author's opinion this is one of the most convincing proofs of the greater efficiency obtained by the arrangement of retarders suggested in this Paper, quite apart from any question of " chasers."

The Author hopes that, by the information given in this Paper and also in the Appendices, he has aroused interest in the question of effecting economies in railway operation by drastic modernization at marshalling yards, where such economies are long overdue.

He also hopes that, by the example set out in Figs 9, Plate 1, the importance of the higher hump and provision of secondary retarders has been established. Here, it will be seen that a slow-running wagon, braked to run at a correct buffing speed into a nearly full siding, may be followed by a fast running wagon, braked to clear that preceding, and yet retain sufficient velocity so as to run right down an adjacent empty siding and stop at the appropriate position. The use of chasers in this example is not intended and, in fact, they are not required.

These means of overcoming the wasteful incidence of " pushing down," with consequent delays, cannot, unfortunately, be readily assessed in terms of reduced running costs, seeing that circumstances are alleviated away from the site of the yard in question and may, in fact, extend through

lengths of running lines and running loops into other yards at remote locations. The improvements resulting at these latter places, generated by the vast improvements at the one original yard which has been specially modernized, influence traffic movements even farther afield, because a chain reaction is set up and an assessment of savings becomes almost endless and may extend into other Railway Regions. The improvements might even render unnecessary the continued operation of these other yards, so that it is quite impossible to make any precise claims in this Paper as to the extent of the benefits which could accrue.

Acknowledgements

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Finally, the Author would be ungenerous if he omitted to record thanks to the Sociéte Nationale des Chemins de fer Français, through Mr Marchand, for the facilities granted to make inspections of French marshalling yards, and to Mr Cauchois.

The Paper is accompanied by four photographs and six sheets of diagrams and drawings, from which the half-tone page plates, the folding Plates 1 and 2, and the Figures in the text have been prepared, and the following four Appendices.

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5. "One-Man Control of Hump Shunting." *Rly Gaz.*, vol. 97, No. 15, p. 405 (10 Oct. 1952).
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APPENDIX 1

Derivation of Formulae for Motion of Wagons under Gravity down Slopes of Uniform Gradient

Symbols

h_1 denotes level, in feet, at start of run
h_2 ,, level, in feet, at end of run
v_1 ,, initial velocity, in feet per second
v_2 ,, final velocity, in feet per second
s ,, length, in feet, of run on one gradient
(Suffix $_G$ on inclined slope, suffix $_L$ on level line)
t ,, time, in seconds, taken to cover distance s
μ ,, coefficient of friction, taking account of kinetic energy of wheels
W ,, weight of wagon including wheels and axles
C ,, coefficient by which total mass of wagon should be multiplied to take account of effect of wheels and axles on the kinetic energy of the wagon $\left(\text{that is, K.E.} = \frac{1}{2} \cdot \frac{CWv^2}{g}\right)$. Typical values of C are given in Table 1.

a ,, acceleration coefficient $= \left\{\frac{h_1 - h_2}{s_G} - \mu\right\}$

f ,, acceleration factor $= \frac{a}{C}$

f_1 ,, acceleration symbol

g is taken as 32·2 feet per second per second.

Calculation of v_2

In *Fig. 11*:

$$\text{K.E. at point 1} = \frac{1}{2} \cdot \frac{CW}{g} \cdot v_1^2$$

$$\text{K.E. at point 2} = \frac{1}{2} \cdot \frac{CW}{g} \cdot v_2^2$$

Work against friction between points 1 and 2 $= \mu W s_G \cos\alpha$ ($\cos\alpha \simeq 1$)
Loss of potential energy between 1 and 2 $= W(h_1 - h_2)$
Loss of K.E. + Loss of P.E. = Work done against friction
that is, $\frac{1}{2} \cdot \frac{CW}{g}(v_1^2 - v_2^2) + W(h_1 - h_2) = \mu W s_G$

$$\therefore \mu s_G = \frac{C}{2g}(v_1^2 - v_2^2) + (h_1 - h_2) \quad . \quad . \quad . \quad . \quad (1)$$

From equation (1):

(*a*) v_2 can be calculated, which becomes v_1 in the calculation for the next gradient down the slope.
(*b*) The distance run to rest down an incline can be calculated, and is s_G when $v_2 = 0$.

The coefficients of friction in *Fig. 12* have been calculated from wagon tests, using equation (1), and account has thus been taken of the effect of the rotation of the wheels and axles and of all incidental frictions on straight track. Using these values of μ, Newton's Laws of Motion may be applied in the same way as for a block sliding down a rough inclined plane.

TABLE 1.—TYPICAL VALUES OF COEFFICIENT C

No.	Type	Tare weight : tons	C empty	Gross weight : tons	C loaded	Wheel-base : feet	Overall length : feet
	British Railways standard wagons						
1	8-ton banana	8·85	1·112	16·85	1·059	9	20·5
2	8-ton cattle	7·65	1·130	15·65	1·063	11	21·5
3	12-ton insulated	10·9	1·091	22·9	1·043	15	24
4	12-ton covered	7·55	1·131	19·55	1·051	10	20·5
5	12-ton container	6·05	1·164	18·05	1·055	10	20·5
6	13-ton soda-ash	7·1	1·140	20·1	1·049	10	20·5
7	13-ton shock	8·55	1·116	21·55	1·046	10	20·5
8	13-ton high (wood)	7·45	1·133	20·45	1·049	10	20·5
9	13-ton high (steel)	7·25	1·137	20·25	1·049	10	20·5
10	16-ton mineral	7·6–7·9	1·130	23·6–23·9	1·042	9	19·5
11	20-ton brake	20	1·049	—	—	16	27
12	20-ton grain	9·75	1·102	29·75	1·033	10·5	24·5
13	22-ton tube	10·35	1·096	32·35	1.031	17·5	33·5
14	24-ton hopper, covered	10·65	1·093	34·65	1·029	10·5	24·5
15	24½-ton coal	10·1	1·098	34·6	1·029	12	24·5
16	24½-ton hopper, open	9·8	1·101	34·3	1·029	12	24·5
17	27-ton iron ore, tippler	7·7	1·129	34·7	1·029	9	19·5
18	42-ton Quint bolster bogie	21·95	1·090	63·95	1·031	—	55
19	42-ton plate bogie	18·3	1·108	60·3	1·033	—	55
	Former L.N.E.R. types differing from standard vehicles						
20	13-ton open	6·0	1·165	19	1·052	10	20·5
21	20-ton open	9·3	1·106	29·3	1·034	12	24·5
22	20-ton tube	9·8	1·101	29·8	1·033	17·5	30

Fig. 11

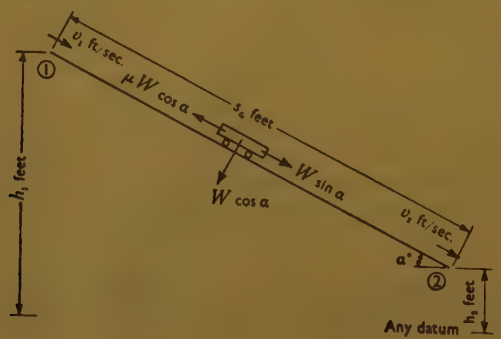
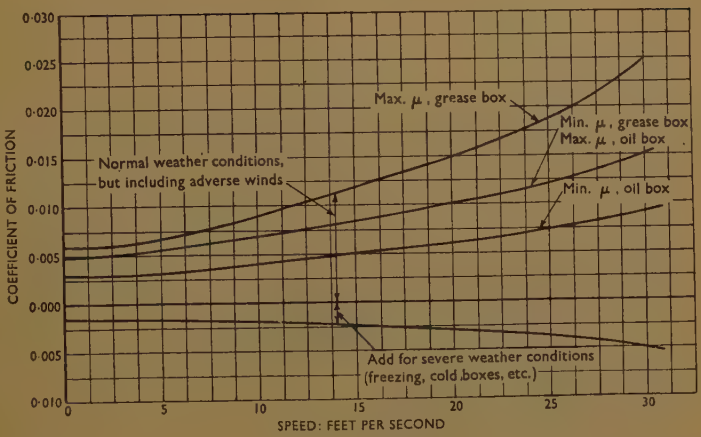


Fig. 12



SUGGESTED DESIGN VALUES OF COEFFICIENT OF FRICTION FOR STRAIGHT TRACK

Calculation of t

From *Fig. 11*, remembering that $\cos\alpha \simeq 1$,

Force down incline $= P = W(\sin\alpha - \mu\cos\alpha)$

$$= W\left(\frac{h_1 - h_2}{s_G} - \mu\right)$$

In the formula: $$P = \frac{CW}{g} \cdot f_1$$

$$f_1 = \frac{d^2s}{dt^2} = \frac{Pg}{CW}$$

Whence $$s_G = \frac{Pt^2g}{2CW} + At + B$$

Putting $t = 0$, the constants of integration become v_1 and 0 respectively.

Hence $$s_G = \frac{Pt^2g}{2CW} + v_1t$$

or $$s_G = v_1t + \frac{g}{2C}\left(\frac{h_1 - h_2}{s_G} - \mu\right)t^2 \quad . \quad . \quad . \quad (2)$$

From which t may be calculated.

Calculation of s_L

$$P = \frac{CW}{g} \cdot f_1 = \frac{CW}{g} \cdot v \cdot \frac{dv}{ds}$$

$$\therefore \int P \cdot ds = \frac{CW}{g}\int v \cdot dv.$$

$$Ps_L = \frac{1}{2} \cdot \frac{CW}{g} \cdot v^2 + A \qquad \text{When } s_L = 0,\ v = v_1,\ \therefore A = -\frac{CWv_1^2}{2g}$$

$$s_L = \frac{1}{2} \cdot \frac{CW}{gP}(v^2 - v_1^2)$$

$$= \frac{1}{2}\frac{C}{g\mu}(v_1^2 - v^2) \text{ since } P = -W\mu$$

$$\therefore\ s_L = \frac{C(v_1^2 - v_2^2)}{2g\mu} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

$$\text{and } t = \frac{2s_L}{v_1 + v_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

From equation (3), s_L can be calculated, and putting $v_2 = 0$ in (3) and (4) gives the probable distance and time of the run to stop on a level track.

Fig. 13

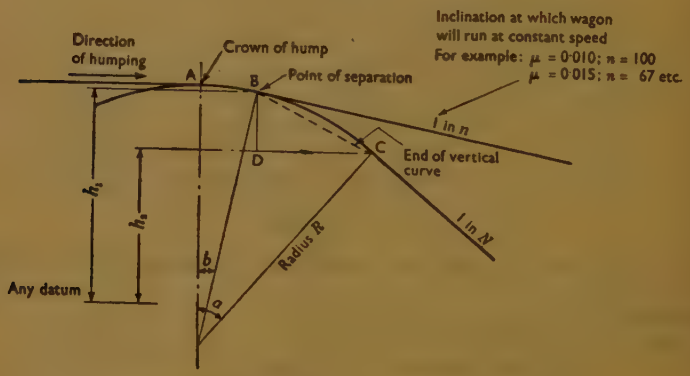


TABLE 2.—SUGGESTED EFFECT OF CURVES AND SWITCHES ON COEFFICIENT OF FRICTION

Wheelbase : feet	Speed : ft/sec.	Radius : chains	*Increase* in μ over value on straight track
Up to 10	Up to 10	Down to 8	0·0032
„	10 to 20	„	0·0044*
10 to 15	Up to 10	„	0·0047
„	10 to 20	„	0·0066
15 to 20	Up to 10	„	0·0062
„	10 to 20	„	0·0088

These figures cover switches.

* Corresponds to an increase in μ of 0·04 per cent per degree of curvature.

APPENDIX 2

MOTION UNDER GRAVITY DOWN VERTICAL CURVE AT HUMP—APPROXIMATE METHOD

At B in *Fig. 13*, $b = 1/n$ = value of μ at humping speed

At C, $a = 1/N$ = initial gradient at end of vertical curve

$$s_Q = \widehat{BC} \simeq R(a - b) \qquad (a \text{ and } b \text{ in radians})$$

Vertical drop $BD = h_1 - h_2 = R(\cos b - \cos a)$

If v_1 is the humping speed (which applies between A and B) and v_2 is the speed at C, then substitution for s_Q and $(h_1 - h_2)$ in equations (1) and (2) gives

$$\mu R(a - b) = \frac{C}{2g}(v_1^2 - v_2^2) + R(\cos b - \cos a) \quad \ldots\ldots \quad (5)$$

and $$R(a - b) = v_1 t + \frac{g}{2C}\left\{\frac{(\cos b - \cos a)}{a - b} - \mu\right\}t^2 \quad . \quad . \quad . \quad . \quad (6)$$

from which v_2 and t may be calculated.

APPENDIX 3

Examples of the Use of Design Curves

Slowest-running oil-box wagon into full sorting siding under severe weather conditions
(See wagon 1 in Figs 9, Plate 1)

Consideration of equation (1) in Appendix 1 shows that the final velocity is a minimum on a given length of a fixed slope if the coefficient C is a maximum *when the wagon is accelerating.*

From Table 1, wagons 5 and 20 give $C_{max} = 1{\cdot}165$ and $W = 6$ tons.

(1) *From Crown of Hump to End of Vertical Curve* (*Appendix 2*)

Humping speed = 2·5 ft/sec. (Average wagon length is 20 feet and this speed results in 8-second spacing of wagons over hump.)

From *Fig. 12* $\mu = 0{\cdot}0065$
Hump V.C. radius $R = 11$ chains $= 726$ feet
At point of separation, slope $= \mu \simeq 0{\cdot}0065$ radian
$= 0° 22' 20{\cdot}73''$
$\cos \mu = 0{\cdot}9999788$
Arc length AB in *Fig. 13* $= \mu R = 4{\cdot}72$ feet
At end of vertical curve, slope $= \frac{1}{18} \simeq 0{\cdot}0556$ radian
$= 3° 10' 59''$
$\cos \frac{1}{18} = 0{\cdot}9984572$
Arc length AC in *Fig. 13* $= \frac{1}{18}R = 40{\cdot}33$ feet
Vertical drop BD $= R(\cos \mu - \cos \frac{1}{18})$
$= 1{\cdot}10$ feet
Chord length BC $\simeq$ Arc length BC
$= 40{\cdot}33 - 4{\cdot}72$
$= 35{\cdot}61$ feet
Chord gradient $= 1{\cdot}1$ in 35·61
$= 1$ in 32·4

(*a*) *From crown of hump to point of separation* (A *to* B *in Fig. 13*)

Constant speed $v_1 = v_2 = 2{\cdot}5$ ft/sec.
Distance $= 4{\cdot}72$ feet
Time taken $= 1{\cdot}89$ second

(*b*) *From point of separation to end of vertical curve* (B *to* C *in Fig. 13*)

Gradient is 1 in 32·4 for 35·61 feet.

To obtain the acceleration factor the value of the coefficient of friction is taken for the average speed on the gradient under consideration. It is thus necessary to estimate an approximate value of v_2 at this stage. The accuracy of this estimate can be checked quickly by the following procedure, using Figs 8, Plate 1, and Fig. 10, Plate 2; the degree of agreement required will become apparent with experience.

v_1 for B to C $= 2{\cdot}5$ ft/sec. ($= v_2$ from 1(*a*) above)
v_2 for B to C is estimated as, say, 7·5 ft/sec.
Average speed $= 5$ ft/sec.
From *Fig. 12*, $\mu = 0{\cdot}0073$
Gradient $= 1$ in 32·4
From point 1 in Figs 8, Plate 1,
$a = 0{\cdot}0235$ and $f = a/C = 0{\cdot}02$

In Fig. 10, Plate 2, AB represents acceleration factor $f = 0{\cdot}02$; points A (v_1, t_1, s_1) and B (v_2, t_2, s_2) represent the beginning and end of the run respectively. The time and distance co-ordinates refer to axes through the point, on the same acceleration-factor line, which represents the start of the wagon from rest. If the wagon is decelerating, the origin is the point representing the wagon when it comes to rest.

That is: if accelerating, $s_2 = s_1 +$ distance run
if decelerating, $s_2 = s_1 -$ distance run

Point A in Fig. 10, Plate 2
$v_1 = 2{\cdot}5$ ft/sec.
$\therefore\ s_1 = 4{\cdot}9$ feet
and $t_1 = 3{\cdot}87$ seconds

Point B in Fig. 10, Plate 2
$s_2 = s_1 + 35{\cdot}61 = 40{\cdot}51$ feet
$\therefore\ v_2 = 7{\cdot}2$ ft/sec.*
and $t_2 = 11{\cdot}2$ seconds

Time taken $= t_2 - t_1 = 7{\cdot}33$ seconds

(and) $= \dfrac{\text{distance run}}{\text{average speed}} = \dfrac{2(s_2 - s_1)}{v_2 + v_1} = 7{\cdot}35$ seconds †

(2) *First Gradient*

The gradient is 1 in 18 for 140 feet
$v_1 = 7{\cdot}2$ ft/sec. ($= v_2$ from 1 (*b*) above)
v_2 is estimated as, say, 20 ft/sec.
Average speed = 13·6 ft/sec.
From *Fig. 12*, $\mu = 0{\cdot}0103$ and gradient $= \frac{1}{18}$
From point 2 in Figs 8, Plate 1,
$a = 0{\cdot}045$ and $f = a/C = 0{\cdot}039$
In Fig. 10, Plate 2, CD represents $f = 0{\cdot}039$

Point C
$v_1 = 7{\cdot}2$ ft/sec.
$\therefore\ s_1 = 20{\cdot}8$ feet
and $t_1 = 5{\cdot}75$ seconds

Point D
$s_2 = s_1 + 140 = 160{\cdot}8$ feet
$\therefore\ v_2 = 20$ ft/sec.
and $t_2 = 16$ seconds

Time taken $= t_2 - t_1 = 10{\cdot}25$ seconds

(and) $= \dfrac{2(s_2 - s_1)}{v_2 + v_1} = 10{\cdot}3$ seconds

(3) *Second Gradient to Primary Retarder*

The gradient is 1 in 50 for 78·6 feet
$v_1 = 20$ ft/sec. (v_2 from 2, above)
v_2 is estimated as, say, 21 ft/sec.
Average speed = 20·5 ft/sec.
From *Fig. 12*, $\mu = 0{\cdot}0132$ and gradient $= \frac{1}{50}$
From point 3 in Figs 8, Plate 1,
$a = 0{\cdot}0068$ and $f = a/C = 0{\cdot}0058$
In Fig. 10, Plate 2, EF represents $f = 0{\cdot}0058$

Point E
$v_1 = 20$ ft/sec.
$\therefore\ s_1 = 1{,}072$ feet
and $t_1 = 107{\cdot}5$ seconds

Point F
$s_2 = s_1 + 78{\cdot}6 = 1150{\cdot}6$ feet
$\therefore\ v_2 = 20{\cdot}8$ ft/sec.
and $t_2 = 111{\cdot}5$ seconds

Time taken $= t_2 - t_1 = 4$ seconds

(and) $= \dfrac{2(s_2 - s_1)}{v_2 + v_1} = 3{\cdot}86$ seconds

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* The estimated value of 7·5 for v_2 is sufficiently accurate for this calculation, since for $v_2 = 7{\cdot}2$ the average speed is 4·85 ft/sec. and from *Fig. 12* the coefficient of friction is still 0·0073.

† Since the wagon is accelerating at a constant rate the time taken is the distance run divided by the average speed and a comparison with the time read from Fig. 10, Plate 2, provides a check that no error has been made in the use of this Figure.

At this stage it should be noted that the maximum permitted speed of impact with the wagons already in the sorting siding is 5 feet per second (3·5 miles per hour). In this case the siding is almost full, so the speed at the clearance point should be 5 feet per second. It is necessary therefore to work back from the clearance points to the primary retarder, where the previous calculation ended, in order to determine whether braking, if required, is within the capacity of the retarder.

(4) *Last Gradient before Clearance Points*

Gradient is 1 in 250 for 268 feet
$v_2 = 5$ ft/sec. (see note above)
v_1 is estimated as, say, 9 ft/sec.
Average speed = 7 ft/sec.
From *Fig. 12*, $\mu = 0{\cdot}0079$ and gradient is 1/250
By inspection (point 4 in Figs 8, Plate 1)
$a = -0{\cdot}0039$ and $f = a/C = -0{\cdot}0034$
The wagon is decelerating, so $s_2 = s_1 -$ distance run
In Fig. 10, Plate 2, GH represents $f = 0{\cdot}0034$

Point G	Point H
$v_2 = 5$ ft/sec.	$s_1 = s_2 + 268 = 383{\cdot}4$ feet
$\therefore\ s_2 = 115{\cdot}4$ feet	$\therefore\ v_1 = \mathbf{9{\cdot}15}$ ft/sec.
and $t_2 = 46$ seconds	and $t_1 = 83{\cdot}8$ seconds

Time taken $= t_1 - t_2 = 37{\cdot}8$ seconds

(and) $= \dfrac{2(s_1 - s_2)}{v_1 + v_2} = \mathbf{37{\cdot}9}$ seconds

(5) *Secondary Retarder*

Assumed effective length * = 23 feet
Energy absorption capacity = 5,500 ft-lb/ft/axle
= 253,000 ft-lb.

In this example for retarding, wagon 22 of Table 1, having a gross weight of 29·8 tons, is taken as the heaviest two-axle wagon that will be humped. It is conservative to use this weight for estimating the maximum entry speed to the retarder.

Energy to be absorbed by retarder $= \dfrac{1}{2} \cdot \dfrac{CW}{g}(v_1^2 - v_2^2)$

$\not> 253{,}000$ ft-lb.

$v_2 = 9{\cdot}15$ ft/sec. (from 4 above)

$$\therefore\ v_1^2 \not> \frac{253{,}000 \times 32{\cdot}2 \times 2}{29{\cdot}8 \times 2{,}240 \times 1{\cdot}033} + 9{\cdot}15^2 = 319{\cdot}5$$

$\therefore\ v_1 \not> 17{\cdot}85$ ft/sec.

Let the wagon in this case enter at $v_1 = 17{\cdot}5$ ft/sec.
Energy absorbed for lightest wagon = 54,100 ft-lb.
$\equiv$ 22 per cent capacity
Energy absorbed for heaviest wagon = 239,000 ft-lb.
$\equiv$ 95 per cent capacity

Time taken $= \dfrac{\text{length of retarder}}{\text{average speed}} = 2{\cdot}21$ seconds †

---

* The assumed effective length of the retarder is 6–7 feet less than the overall length.
† It is assumed that deceleration is uniform throughout length of retarder.

(6) *Gradient between Retarders*

Gradient is 1 in 85 for 330·5 feet
$v_2 = 17{\cdot}5$ ft/sec. (v_1 from 5, above)
v_1 is estimated as, say, 17·5 ft/sec.
Average speed = 17·5 ft/sec.
From *Fig. 12*, $\mu = 0{\cdot}0118$ and gradient $= \frac{1}{85}$
For point 6 in Figs 8, Plate 1,
$a = 0$ and $f = 0$
A steady velocity of 17·5 ft/sec. may be assumed since the acceleration factor is negligible.

$$\therefore\ v_1 = 17{\cdot}5 \text{ ft/sec. and time taken} = \frac{330{\cdot}5}{17{\cdot}5} = 18{\cdot}9 \text{ seconds}$$

(7) *Primary Retarder*

Assumed effective length* = 62·5 feet
Energy absorption capacity = 5,500 ft-lb/ft/axle
= 687,000 ft-lb.
$v_1 = 20{\cdot}8$ ft/sec. (v_2 from 3, above)
$v_2 = 17{\cdot}5$ ft/sec. (v_1 from 6, above)
Energy absorbed for lightest wagon = 30,800 ft-lb.
≡ 4·5 per cent capacity
Energy absorbed for heaviest wagon = 135,500 ft-lb.
≡ 20 per cent capacity

$$\text{Time taken} = \frac{\text{length of retarder}}{\text{average speed}} = 3{\cdot}6 \text{ seconds}$$

The heaviest and fastest wagon running free enters the primary retarder at 24·1 feet per second (calculated from curves in the same way as the above example) and the energy of the wagon is 620,000 ft-lb. In the case of an accident in the yard below the primary retarder, any wagon can be stopped by the application of up to 90 per cent of the capacity of the primary retarder. Any further wagons can be braked manually at the hump crown.

(8) *Summary*

Position in yard	Distance from crown of hump: feet	Time from crown of hump: seconds	v_2 ft/sec.
1. (*a*) Crown to separation point . .	4·72	1·89	2·5
(*b*) Sepn point to end of V.C. . .	40·4	9·24	7·2
2. Gradient 1 in 18	180·4	19·54	20
3. Gradient 1 in 50 (to primary retarder)	259	23·40	20·8
7. Primary retarder	328	27·00	17·5
6. Gradient 1 in 85 (to secondary retarder)	658·5	45·90	17·5
5. Secondary retarder	688	48·11	9·15
4. Gradient 1 in 250 (to clearance point)	956	86·01	5

* The assumed effective length of the retarder is 6–7 feet less than the overall length.

(9) *Example of Wagon running to Rest—Slowest-Running Oil-box Type*

(See wagon No. 3 in Figs 9, Plate 1).
The gradient is 1 in 250 for 842 feet (below clearance point)
$v_1 = 7{\cdot}2$ ft/sec.; $v_2 = 0$; average speed = 3·6 ft/sec.
From *Fig. 12*, $\mu = 0{\cdot}0067$ and gradient = $\frac{1}{250}$
By inspection (point 9 in Figs 8, Plate 1),
$a = -0{\cdot}0027$ and $f = a/C = -0{\cdot}0023$
In Fig. 10, Plate 2, point L represents $f = 0{\cdot}0023$ and $v_1 = 7{\cdot}2$ ft/sec.
$\therefore s_1 = 348$ feet and $t_1 = 97$ seconds

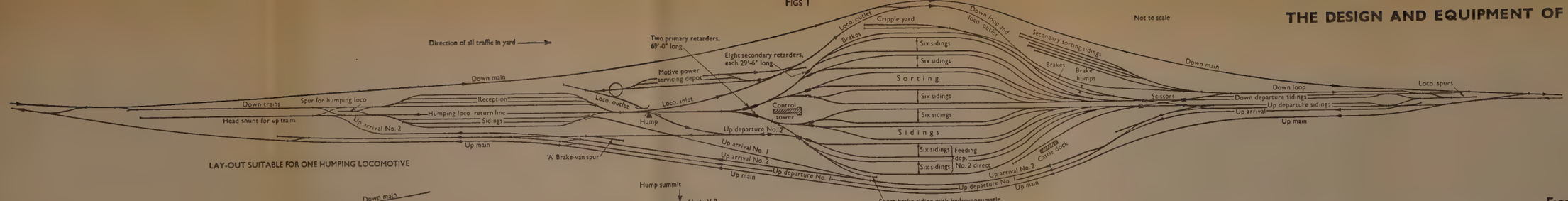
Distance run to stop = 348 feet
Time taken = 97 seconds

APPENDIX 4.—DETAILS OF SOME HUMP MARSHALLING YARDS

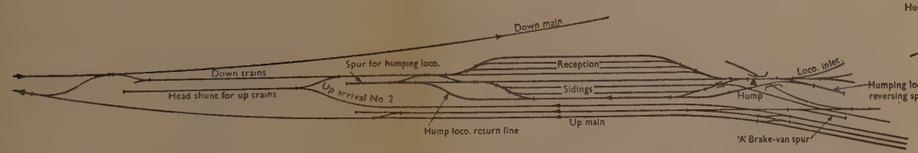
Yard	Year opened	Number of			Distance, hump apex to clearance point: feet		Distance, hump to king switches: feet	Vertical radius of hump: feet	Initial gradient: 1 in	No. of retarders		Sorting sidings per retarder or per secondary or tertiary retarder	Remarks
		Reception sidings	Sorting sidings	Departure sidings	Longest	Shortest				Primary	Secondary		
Toton Up	1950	10	37	Nil	910	750	120	660	20	4		1 in 9·25	
Toton Down	1939	3	34	Nil	835	630	124	660	18	4		1 in 8·5	
Whitemoor Up	1929	10	41	11	800	665	114	528	18	4		1 in 10·25	
Whitemoor Down	1933	10	43	Nil	975	750	100	528	17	2		1 in 21·5	Mostly empty wagons
Hull Inwards	1935	6	30	Nil	810	745	95	700	18	4		1 in 7·5	
Le Bourget	1943	10	31	Nil	720	720	82	720	20	4		1 in 7·8	Details are for "Impair"
Villeneuve St. Georges	1950	18	48	21	830	830	92	815	20	6		1 in 8	Two-way yard
Achères	1948	11	31	8	830	830	92	815	18	5		1 in 6·2	Two-way yard
Ripple Lane	Design	8	50	4	1045	796	148	528	18	2	8	1 in 6·3	Also departure from 12 sorting sidings
Temple Mills	Design	12	50	8	1050	830	138	726	18	2	8	1 in 6·3	Two-way yard Also departure from 12 sorting sidings
Banbury Up	1931	6	17	Nil	560	340	55	400	20	None		—	Two-way yard
Severn Tunnel Jcn. Up	1939	4	21	Nil	Ladder track		105	800	20	None		—	
Severn Tunnel Jcn. Down	1939	4	19	Nil	600	420	45	—	20	None		—	
Feltham Up	1921	8	19	Nil	443	685	158	520	26	None		—	
Feltham Down	1921	10	20	Nil	525	725	255	690	26	None		—	

FIGS 1

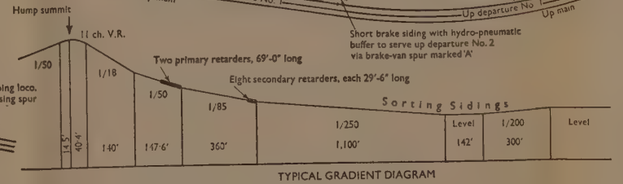
Not to scale



LAY-OUT SUITABLE FOR ONE HUMPING LOCOMOTIVE



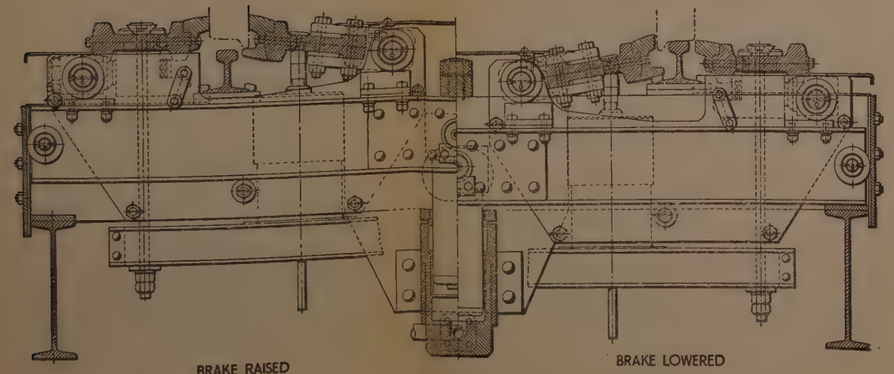
ALTERNATIVE LAY-OUT TO PERMIT ECONOMIC USE OF TWO HUMPING LOCOMOTIVES



TYPICAL GRADIENT DIAGRAM

TYPICAL LAY-OUT FOR TWO-WAY MARSHALLING YARD

FIG. 3



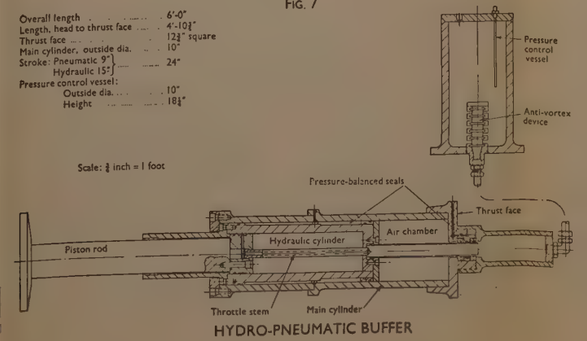
BRAKE RAISED

BRAKE LOWERED

CROSS-SECTION OF HYDRAULIC RETARDER

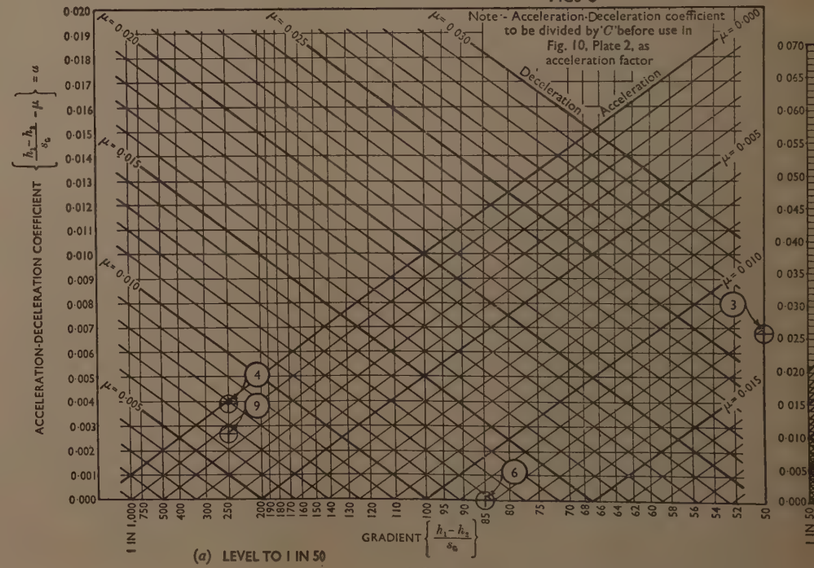
FIG. 7

Overall length ..... 6'-0"
Length, head to thrust face ..... 4'-10½"
Thrust face ..... 12½" square
Main cylinder, outside dia. ..... 10"
Stroke: Pneumatic 9"
Hydraulic 15" ..... 24"
Pressure control vessel:
Outside dia. ..... 10"
Height ..... 18½"



HYDRO-PNEUMATIC BUFFER

FIGS 8

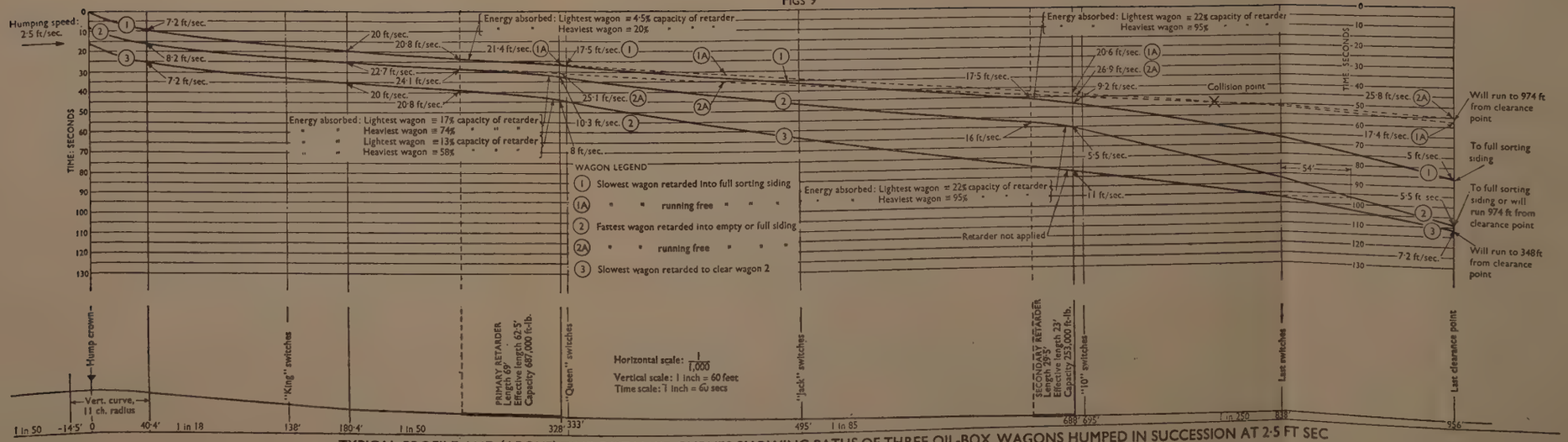

Note:- Acceleration-Deceleration coefficient to be divided by 'C' before use in Fig. 10, Plate 2, as acceleration factor
Deceleration
Acceleration
ACCELERATION-DECELERATION COEFFICIENT $\left\{\frac{h_1-h_2}{s_6}-\mu\right\}=a$
GRADIENT $\left\{\frac{h_1-h_2}{s_6}\right\}$
1 IN 1,000
1 IN 50

(a) LEVEL TO 1 IN 50

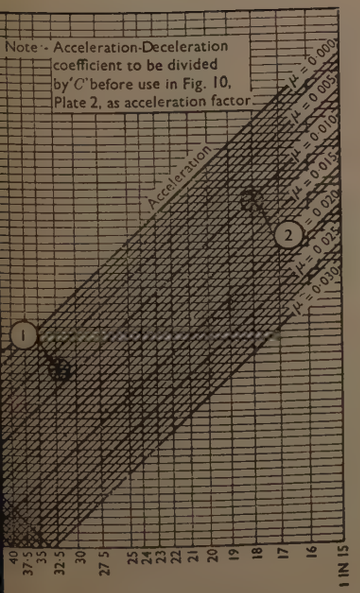
ACCELERATION-COEFFICIENT CURVES

WILLIAM CLOWES & SONS, LIMITED: LONDON

FIGS 9



TYPICAL PROFILE AND (ABOVE) TIME-DISTANCE CURVES SHOWING PATHS OF THREE OIL-BOX WAGONS HUMPED IN SUCCESSION AT 2·5 FT SEC



(*b*) 1 IN 50 TO 1 IN 15

R. E. SADLER

APPENDIX 4.—DETAILS OF SOME HUMP MARSHALLING YARDS (CONTINUED)

Yard	Year opened	Number of			Distance, hump apex to clearance point: feet		Distance, hump to king switches: feet	Vertical radius of hump: feet	Initial gradient: 1 in	No. of retarders		Sorting sidings per retarder or per secondary or tertiary retarder	Remarks
		Reception sidings	Sorting sidings	Departure sidings	Longest	Shortest				Primary	Secondary		
Ernest Norris, Southern U.S.A. Railway . .	—	—	56	—	—	—	—	—	—	1	7	1 in 8	
Allentown Westbound, U.S.A. .	—	—	18	—	—	—	—	—	—	3		1 in 6	
North Platte Union Pacific, U.S.A. . . .	—	—	41	—	—	—	—	—	—	1–2–6		1 in 6·9	
Milwaukee Air Line, U.S.A. .	—	—	25	—	—	—	—	—	—	1	4	1 in 6·2	Automatic speed control in retarders

NOTES.—Although no precise rules can be laid down, it is generally considered that a movement of 1,500 to 2,000 wagons per day through a yard justifies the provision of retarders. Further, as a general guide only, and based upon the performance of British Railways wagon stock at present in use, up to 18 sorting sidings may be worked quite effectively by a low hump and no retarders (however, at least two "chasers" are required); 18 sorting sidings and up to 29, by one set of retarders; 30 sorting sidings and over, by primary and secondary retarders.

Having regard to a number of factors, a single hump, whether located in a one-way or two-way yard, is not considered capable of dealing with more than 6,500 wagons in three consecutive shifts, that is, 24 hours. The S.N.C.F., with longer wagons, take 4,500–5,000 wagons on the same basis. It should not be overlooked that the longer wagons of the French railways result in better spacing having regard to the identical humping speeds used in both countries. This factor alone reduces the risk of collisions.

Discussion

Mr J. I. Campbell said that since the publication of Mr Kubale's Paper [1] 15 years previously there had been many important developments, particularly in France and the United States, so the present Paper was very welcome. The information given in it was, in certain respects, more extensive than the ground covered by Mr Kubale. The information in the Appendices was particularly valuable.

Most of the data had been obtained from practical experiments at Whitemoor. It was the first time that the running characteristics of British railway wagons had been recorded. It was certain, therefore, that for many years the Paper would serve as a useful reference guide and would be found in the drawing offices of British Railways.

Apart from technical data the Author had propounded several new and interesting variations in what seemed to have become accepted standard practice in lay-out design in Great Britain. During the past year or two Mr Campbell had had many discussions with the Author about marshalling yards and he was largely in agreement with the views expressed in the Paper.

He was well aware that those views were not unreservedly accepted by all interested parties and he therefore hoped that during the discussion there would be some constructive criticism of the Author's suggested innovations. It should be realized that in a small country of intensive freight traffic such as Britain there were only five mechanized marshalling yards. It seemed obvious therefore that there must be a wide field for development on mechanized lines, especially when consideration was given to the considerable economies resulting from the provision of large marshalling yards at strategic points and the closing down of out-of-date yards.

That technique had been adopted and developed energetically in both France and the United States. It produced cheaper operation, quicker transit, and the employment of fewer wagons. In France, it was estimated that those developments had resulted in a 20-per-cent decrease in the number of wagons which passed through the marshalling yards.

The principal suggestion made by the Author concerned secondary retardation, which would be an innovation in Britain and, indeed, in Europe, though not in the United States, where it was quite common. Mr Campbell thought that the Author's reasoning was sound and that the introduction of secondary braking would go a long way towards solving two important present-day problems on British railways—first, pushing down, and, secondly, the damage to wagons, which was undoubtedly high. There was another benefit, which could not be assessed in terms of money—the number of satisfied customers who received their goods all in one piece.

[1] See ref. 1, p. 776.

Nor should the district engineer be forgotten ; he was enabled to repair his sidings without first having to remove several hundred tons of spillage.

With only one set of brakes an operator was expected to perform both functions of maintaining the separation of the cuts and regulating the distance run. In the very short distance of a single retarder that was rather too much to expect. If secondary brakes were available, the cut could be allowed to leave the primary brake at a slightly higher velocity with the assurance that the distance it still had to travel could be regulated in the secondary brake.

Furthermore, the cuts could be allowed to pass through the switching area immediately below the retarder at a higher speed, diminishing the chance of a collision. In any event, the case for secondary braking as propounded by the Author was worth very careful consideration, even to the extent of incorporating it in a yard on an experimental basis. That would produce positive proof which could not be obtained by discussion.

Mr J. C. Kubale said that if the operating authorities wanted any evidence of the advantages of modernization, they needed only to look at a few yards in Great Britain and at yards in France and the United States, where it seemed that ample dividends were being reaped from capital investment. But the marshalling yard itself was only one of several problems connected with the ideal of getting more ton-miles per day from each wagon. The aim was to get a better paying load and a greater availability of wagons.

On p. 760, the Author had drawn attention to the fact that Mr Kubale, in his earlier Paper, had mentioned a humping speed of 4 feet a second. Admittedly, that was not a normal speed, but he had had in mind some acceptance tests organized by the railways to prove the apparatus. Lower speeds were normal.

The Author had suggested that the length of the switching zone was of minor importance. In the past it had been thought that the zone should be as short as possible, but the Author believed that it did not matter if it were made a little longer to suit certain features. Mr Kubale, on the other hand, thought the limitation of the switching zone was of great importance, because one of the fundamentals of design was that the switching zone should be as short as possible so that the amount of retardation necessary was the minimum, which meant that the cost of providing the brakes was also the minimum. For every additional 100 feet of length Mr Kubale estimated that about 50,000 foot-lb. of retardation would have to be installed for each fan of sidings.

Pushing down was a severe problem and a solution of it would be of great advantage to the operating department. The Author had not gone far enough. He had suggested secondary retarders controlling six sidings, but the need for pushing down generally arose from wagons being pushed over the hump too fast or an error of judgement by the brake operators. The same errors could be made in the yard suggested by the Author, and

there was the added difficulty of two retarders working in series, both of which, according to theoretical calculations, should be operated in a certain manner. Mr Kubale did not know how that could be practicable for a single operator. It might be that a solution of that problem would arise from present American experiments on automatic braking to obtain the speed control of wagons by means of retarders. If the manual element was eliminated more confidence could be placed in the application of the theoretical requirements.

The whole question of primary, secondary, and tertiary retarders seemed to arise from a misconception of the origin of the American-type brake. American brakes were limited in capacity by the height at which the braking rails of retarders could be applied above the top of the running rails (the maximum being about 2½ inches). With a given braking capacity and a certain length of yard, the length of retarders required was known, and a simple calculation showed that if the retarders were distributed in several track leads, less total length of retarders was required.

The Author had referred to remarkable economies achieved by having secondary retarders, but installing a retarder between the hump and the King point would have effected further economy but would raise other problems. When commenting on the length of time required for renewal of the pits at Whitemoor, the Author had failed to point out that those pits were changed because of changes in the type of brakes, and the long time needed for the change-over was abnormal. The present idea was to have a spare brake, and about every 8 yrs the whole brake was taken out; the work could be done in a period which might be described as a long week-end.

Mr Kubale asked how many wagons had been tested to provide the data for *Fig. 12*. Referring to Figs 9, Plate 1, he could find no mention that curve resistance had been taken into account in the calculations in the Appendices. What would happen if a fourth wagon similar to No. 2 followed No. 3? It seemed that it would overtake the previous wagon before the jack points, which was a poor feature of the design of the yard.

Mr D. G. Shipp was interested in the comparisons that had been made between hydraulic and electro-pneumatic retarders. He felt that the most remarkable was that which concerned the time required to make a complete renewal of the retarders, which had been given as 2 months for the hydraulic type, where renewal of the pits was also involved, while the corresponding figure for the electro-pneumatic type was 4 to 8 hours.

The Author had stated that the ease with which the electro-pneumatic brake could be renewed was attributable to the fact that all the work could be carried out above ground level, for no pit was needed below the track; Mr Shipp added that that was also because the whole brake was set down very simply on timbers so that it could be raised as a complete unit by means of jacks and removed from the site on suitable trolleys.

He then showed a number of slides illustrating the procedure of removing and replacing a typical retarder, having a length of 23 metres and an overall weight of 33 tons. The first stage was to remove the pipe connexions to the retarder and the fish plates joining the running rails to the adjacent track. The complete retarder was then jacked up, five jacks on each side, and its place taken by a temporary track laid on temporary timbers. The rail chairs would not be spiked down, but fish plates would be used to attach the temporary rails to the adjacent track. Trolleys were brought up and run underneath the old brake, which was then lowered on to the trolleys by means of the screw jacks and wheeled away. Installation of the new brake involved the same procedure in reverse order.

The next point of comparison concerned the provision of track circuits throughout the length of the retarder. Unlike the electro-pneumatic retarder, it was not possible to provide track circuits within the length of the hydraulic retarder, and that brought some operational disadvantage where it was desired to have fully automatic control of the points or speed control of the retarder. Complete automatic point-setting usually necessitated continuous track circuiting from the hump to the final clearance point. If those track circuits had to be omitted at the retarders, it was necessary to provide some kind of electrical relay storage so that track of the cuts should not be lost as they passed through the non-track-circuited areas. That was a complication compared with the simple track circuit through the retarder, and would use additional relays.

An example of control of the retarder by the speed of the cut passing through it was the installation at the Milwaukee Air Line Yard in the United States. The speed of the cars had to be measured, and a convenient method was to register the time taken as the leading axle of the cut passed over successive short track circuits provided throughout the length of the retarder. Where track circuiting could not be employed, Mr Shipp thought that the timing could be achieved by means of a series of mechanical devices; they would be more complicated and would involve more maintenance than electrical track circuits.

On p. 766, the Author had stated that with a hydraulic retarder the whole length of the brake shoe was in one piece and therefore any application was uniform throughout. If one tire were thicker than another, would the full braking force act substantially on the one wheel? Was that why it was generally accepted that there was a considerable amount of metal "swarf" surrounding hydraulic retarders in comparison with the electro-pneumatic type?

On p. 764 the Author had referred to the point setting at Toton Up yard as being of much later design and completely automatic. That was not the first installation of complete automatic point operation in England; the Hull Inwards yard installation had been made 15 years earlier in 1935.

Mr A. R. Dunbar said that three questions arose: first, was the topic worth while; secondly, should an engineer talk about it; and thirdly,

had that engineer found the right answers? There was no difficulty in giving a forthright affirmative answer to the first question. Sometimes there was an impression that shunting was a diversion indulged in by railway operators for their own amusement. The time it took to shunt a given number of wagons or the amount of money spent on the job never hit the headlines—and it was time it did. Freight engines were used for shunting for about half the total time they were in traffic. During 1952, on British Railways, freight shunting engine-hours had totalled 17 million, and freight train engine-hours 16 million. Shunting was an item of great importance in operating expenditure. Its importance in transit time was equally significant. Each shunting yard through which a wagon had to pass on its journey meant another delay, and each time a train was split up there was a risk of damage and missed connexions. It was axiomatic that the fewer yards a wagon had to pass through, the better were its chances of getting through safely and quickly. To design modern yards to take the place of a number of small ones was vitally important to economical working and good services.

The time was ripe for a general review of British marshalling yards. The advent of increased competition—directly, between road and rail; and indirectly, in the export markets—made it a matter of urgency to speed up and cheapen the freight services.

Was it the engineer's job? Should he talk about it? The Author believed that the Chief Regional Officer should send for his technical officers when the question arose. It was not exclusively their job, but they had an important part in it. The breadth of their interest depended on the approach. Some would say that the traffic operator, with knowledge and experience of working marshalling yards under all conditions, knew exactly what he wanted and could lay down a clear specification for gradient, braking, and so on. Others would say that the user or operator should indicate only the general aims and leave the design entirely to the engineers.

Mr Dunbar thought it was essentially a joint matter, to be developed together. It should start with a critical approach beginning with the assumption that all works could be improved. The operator's approach to planning with the engineer might be to say, "I can see the prospect of greatly improved efficiency if you give me a yard to handle 4,500 wagons a day and to shunt fifty main sorts. An effort should be made to reduce to the minimum two weaknesses of present designs—wasteful pushing down of wagons which have not run far enough into the sidings and damage to the goods and wagons by sharp impacts."

The next step was for the engineer to calculate all the ascertainable factors and to give the results. That might be thought highly theoretical and therefore suspect to practical men, but a new work was never undertaken without counting the cost, and it was equally essentially to calculate, in advance, as much as possible about efficiency of performance.

The next step was for those calculations, and the designs that would flow from them, to be examined with the critical eye of the man who was going to do the job. That was the point from which there was constant interplay of interest between the designer and the user. There was always a certain element of risk with a new idea or the adoption of one which had been tried elsewhere under different conditions, but much could be done by observation and calculation to reduce that risk.

In the field of marshalling-yard design the dividends to be reaped were so great that some degree of risk was worth while in any event.

Had the Author the right ideas? It was certain that he had made a valuable contribution to the evidence for the scientific design of marshalling yards. His principal contribution was the working out of the rolling resistances of wagons related to the force of gravity, and from that his calculations for the correct design of gradients and the location of retarders.

Not all his conclusions would command universal acceptance at first. But, whether they carried conviction or not, the attempt must be made to design hump gradients and yard equipment, in a way which would drastically reduce the unproductive time of about 30 per cent now spent in closing down in mechanized yards.

If the attempt were successful, it would raise the capacity of such a yard from 3,500 to 4,500 wagons a day and, with other improvements, a yard with a capacity of 5,000 wagons a day was within reach. If the Author's conclusions could find general acceptance, there was prospect of great savings in engines and men, great improvement in service, and less damage to wagons. With such a capacity it was conceivable that any main line or any large town in Britain could be served by one double-direction yard.

Mr Arthur Moss said that when marshalling yards had been introduced into Great Britain, the view was expressed that it was paradoxical to arrange both steep gradients so that wagons could gain speeds over short distances and brakes to slow them down. How much more paradoxical to provide additional, secondary brakes for the same purpose? Obviously, the economics had to be justified by the possibility of more speedy humping and the possibility of keeping the whole yard working should one of the main retarders be out of commission.

It was on record that the late Mr C. J. Brown, an eminent civil engineer, had said the designer of any mechanized yard should include three essential features—first, gradients; secondly, brakes; and thirdly, automatic points. The Author had dealt with the first two features but had said little about the third.

It had been suggested that the Chief Regional Officer should send for his civil engineer to design him a yard. Mr Moss hoped the C.R.O. would be wise enough to send also for his signal engineer to make sure that it worked.

In Figs 9, Plate 1, the end of the primary retarder was 5 feet from the Queen switches. If the controlling track circuit commenced at the end of the retarder, any wagon entering the track circuit at the same time as the automatic points commenced to throw would be derailed. The speed of the wagon over the Queen switches was shown as 17·5 feet per second. Automatic points would operate in 0·6 second. In that time the wagon travelled about 10·5 feet, and to keep the wagon on the rail under the conditions mentioned the circuit must commence at least 16 to 17 feet on the approach side of the Queen switches. The Author would have to move his brake back 20 feet if it were of the hydraulic type, but if it were of the electro-pneumatic type he could have an insulated joint that distance within the brake. The same remarks applied to the secondary retarder.

The distance there was 7 feet from the switches. If a wagon were to travel 9·2 feet per second, obviously a distance of more than 7 feet was needed to hold the points. Once the wagon had left the secondary retarder and the points commenced to throw, it had to be ensured that the points threw over to the full reverse position before the wagon arrived.

There was little in the Paper about the human element. The successful operation of any mechanized yard was in a large measure dependent upon the human element. Whether a yard had primary retarders or primary plus secondary plus time control, much of the success depended upon the operator. The Author himself had stated, on p. 762, that the degree of retardation would vary at the will of the operator.

Mr G. D. S. Alley said that the gridiron at Edge Hill was not an ordinary shunting yard. It consisted of a system of sidings laid on a bank formed by the excavation from tunnels and cuttings nearby, and worked by gravity. All traffic had to be held at one end of it and the sidings were ordinary ladder sidings. The hook and chain at Edge Hill had still been working in 1950. Would any of the brakes described by the Author still be working after such an interval ?

There was a hook at the outlet of each of the sidings. It was connected to a small chain which gradually increased in weight and strength, so that if there was a real runaway or a whole train going down the sidings, the appropriate length of chain could be pulled out and the slowing down would be gradual. It was easy to maintain and cheap to install, and simply acted in place of sand drags.

In 1932, in South Wales, there had been cause for complaint about the lack of information on the running of vehicles with grease boxes and oil-boxes on different gradients. A coal-hoist was being installed and there had been some doubt about the gradient to use. When a full wagon of coal had been weighed on the weighbridge and then tilted to a gradient of 1 in 8, it often had to be pushed off. When coal traffic was normal and flowing well, trains came straight down the valleys on to the tip and the grease was free, but when trade slackened off they were standing in the

sidings for long periods. It was difficult to find conditions which met all cases.

Dealing with renewals, Mr Alley said that like-for-like replacements of the hydraulic brakes could be carried out at Toton in a normal week-end.

Mr R. L. McIlmoyle said that the Author had had three objectives. The first was to give a full and up-to-date description of modern practice in marshalling yards; he had done that very well and had given a lot of information which was not readily available. His second objective was to sell the need for more marshalling yards. He had put that over fairly well, but it was doubtful whether there were many places where savings of the order given in the Paper could be achieved. His third objective was to sell the need for secondary retarders. He had made a strong case, but it was probable that they were justified only in a number of special cases and not for general adoption in mechanized marshalling yards.

Mr McIlmoyle dealt with the length of time taken to change retarders. The yard he was concerned with had eight hydraulic brakes and a complete spare, and the spare could be installed in a normal week-end. With more experience, it would require less time.

The Author had mentioned three types of brake, but there was a fourth very popular in America but not common on the Continent—the fully electric brake. Mr McIlmoyle had been told that in America the electro-pneumatic type was steadily being replaced by the fully electric type, for which a number of advantages were claimed.

The Author had also omitted to mention a very fine yard near Montreal where the lay-out was much superior to anything which Mr McIlmoyle had seen elsewhere.

*** **Mr M. Marchand,** of the S.N.C.F., Paris, referred to the centralization of marshalling yards. The Author had stated that the reduction in the number of marshalling yards had very important advantages from the point of view of economy in running costs and speed of dispatch—far beyond the most optimistic predictions which could be made by the few technicians who had made a special study of those problems. That should be emphasized, because to many railway workers the construction of modern marshalling yards only raised the spectre of unemployment, which they believed to be always attendant upon mechanization.

But economies in labour were merely secondary effects when compared with the other benefits which could be obtained by the establishment of large modern yards. A considerable reduction in maintenance costs, resulting from the closure of nearby secondary marshalling yards, was accompanied by improvement in dispatching arrangements which, independently of commercial interests, resulted in even larger economies—particularly from the point of view of reduction of rolling stock.

It was certainly very difficult in the planning stage to calculate the overall

*** This contribution was submitted in writing upon the closure of the oral discussion.—Sec. I.C.E.

effect of those factors ; nevertheless, appraisal of them was becoming easier consequent upon the experience gained by the French railways. Between 1946 and 1951, S.N.C.F. had concentrated the marshalling of long-distance traffic into forty big yards, of which seven had been modernized before the war and seven had recently received some modern equipment ; at the same time, fifteen yards had been closed and the work of a score of others had been considerably reduced.

The results obtained had been subjected to various estimations ; for instance, the Dijon marshalling yard had shown economies of the order of 15 per cent of the capital cost. For the scheme as a whole, comparable statistics for traffic and marshalling-yard operations were given in Table 3, which showed that the number of wagon-sortings had been reduced by 9,700,000 ; after making allowance for the number of complete trains made up by manufacturing and mining establishments, the portion of the reduction of wagon movements attributable to the reorganization of the marshalling yards had been estimated at 3,700,000, that was to say, about 6 per cent of the total working.

Furthermore, since the average time spent by a wagon in a marshalling yard was about half a day, it could equally well be stated that approximately 2,000,000 wagon-days could be saved, which represented a reduction in rolling stock of 5,000 to 6,000 wagons. It followed that, at current

TABLE 3

	1946	1948	1951
Number of wagons loaded : millions	10·9	13·5	13·7
Number of wagons handled in yards : millions . . .	60·8	72·1	63·7

French prices, economies in rolling stock alone had almost paid for the outlay involved in the seven new modern marshalling yards completed between 1946 and 1951.

Regarding the distribution of marshalling yards, Mr Marchand pointed out that it was tied up with numerous factors, particularly train loads and wagon loads. The aim of railway operation should be to enable the formation of the greatest possible number of regular fully loaded long-distance through trains. Increasing the average loading of goods trains required an increase in the number of wagons handled by the marshalling yards and consequently a reduction in the number of the latter ; lack of respect for that axiom in many countries had led to the present need for reorganization.

Furthermore, increasing the wagon load decreased the number of wagons to be handled and therefore the number of marshalling yards required ; that was particularly so in France, for between 1946 and 1951

the average wagon load had risen from 13 to 17 (French) tons. As a result, some retrenchment had been possible in the programme of modernization drawn up in 1946. It seemed that when establishing the distribution of marshalling yards, consideration might be given to the eventual use of larger wagons.

So far as the operation of a gravity marshalling yard was concerned, Mr Marchand stated that it depended fundamentally upon the characteristics of the rolling stock, and the greatest possible caution should be exercised when applying the methods used on one railway system to the operation of another. For example, the heavy free-rolling wagons used in the United States justified the use of long braking distances and multiple retarders. But it appeared from current literature that American ideas were changing and that the present tendency in the United States yards was to reduce the number of braking stages.

Furthermore, although most European railways employed " chasers " and slippers to complete the work of single-stage retarders, the Americans did not appear to take the same precautions ; it should be borne in mind, however, that the American type of automatic couplings permitted a higher buffing speed. The numbers of " chasers " employed might depend upon the prevailing policy ; some French yards appeared to employ too many, but the competition of road transport obliged S.N.C.F. to take extra precautions against damage.

The Author believed that two-stage retardation presented a two-fold advantage in (*a*) accelerating the rate of sorting, and (*b*) eliminating the need for " chasers." No experience of that type of installation had been obtained in France, but it was felt that, at least with regard to (*b*) above, two-stage braking would not produce the advantages claimed.

The rate of sorting had to be regulated so as to eliminate the risk of overtaking in the " danger zone," which lay between the last retarder and the siding switch. It was necessary, therefore, to ensure rapid sorting, for the " danger zone " to be short and also for the variation in time taken between hump and retarder to be small. In France, the length of the danger zone ranged up to 90 metres (about 100 yards) when serving eight sidings ; the possibility was envisaged of reducing that length by installing one retarder per six sidings, but research had shown that the use of a three-way switch wasted space and the improvement for a span of six sidings was almost negligible.

The time taken by different trucks to run from hump to retarder was fairly constant in French yards (variation was of the order of 1–2 seconds) ; the characteristics of British rolling stock gave rise to wider variation, and there arose the temptation to iron out the difference by installing an intermediate or " primary " retarder.

But the steep run down from the hump and the congested arrangement of the switches, as described in the Paper, contrasted with American layouts. The primary retarder would be placed at the foot of the hump.

Would the variation of speed at entry to the brake be sufficiently pronounced for the operator to be certain which wagons were good and which were bad runners ?

On the other hand, on p. 762, the Author had suggested that both primary and secondary retarders could be controlled by the same operator, the idea being that he could correct, by means of the secondary, any error he had made when passing a wagon through the primary. Mr Marchand doubted if that would be practicable, since at the high humping speed envisaged, it was quite possible that both retarders might be occupied simultaneously.

With regard to " chasers," the views of S.N.C.F. were at variance with those of the Author, and it was not believed that multiplication of braking stages could lead to any reduction in the number of runners employed. In theory, the operator should bring the wagon to rest in the siding just touching the stationary train. He should, therefore, know the distance to run after the last brake and the rolling characteristics of the wagon concerned, in order to deduce the speed with which the wagon should leave the brake. Errors were, however, inevitable, and Mr Marchand did not think that the operator could achieve greater accuracy with two brakes than with one. The main cause of error of judgement was the variation of rolling friction—a factor which was more apparent in Britain than elsewhere.

S.N.C.F. did not think, therefore, that any economy in the employment of " chasers " could result from the installation of two-stage retarding.

The importance of the question of the number of runners to be employed should not be exaggerated. The possible reduction of personnel was secondary to the greater overall efficiency obtainable by the centralization and mechanization of marshalling. It could not be denied, however, that there was something to be said for the partial elimination of a difficult and somewhat dangerous task. Researches in both Germany and France were leading to the development of automatic or semi-automatic brake control.

The Author, in reply to Mr Kubale's comments upon the speed of humping, pointed out that a test upon four consecutive trains at Whitemoor at 2·5 feet per second had proved rather too much for the retarder operators, since the existing gradients did not engender sufficient clearance between single cuts of wagons. Such a test at 4 feet per second, anywhere in Great Britain, would degenerate into a brake test only, and sorting, if it occurred at all, would be a secondary matter.

Longer initial gradients would be necessary to provide the all-important spacing between wagons which was required, *inter alia*, to effect all the conditions of the signal and telecommunications engineer. To obtain those and secure other benefits resulting from consistent performance was

surely worthwhile when set against a possible additional retardation of 50,000 foot-lb., as suggested by Mr Kubale.

Doubt had been expressed about the ability of the brake operators to perform the functions which had been allocated to them in the specimen calculations. Judging by what the Author had observed at Whitemoor, there should be no difficulty at all; the operators appeared to " sense " the wagons extremely well. They could, however, receive advice of any exceptional case broadcast from the hump cabin through a loud-speaker system.

The Author could not agree with Mr Moss, who was sceptical about the ability of one man to work one primary and four secondary retarders. Having seen one man work, with ease, twelve levers attached to six brakes at Villeneuve St. Georges, the Author was unable to appreciate how any difficulty could arise when one man was called upon to operate only half the number of levers. Since every wagon presented itself twice for attention, prior knowledge at the second brake application was a valuable asset.

The Author could not give any particulars about automatic speed control, but hoped they would soon be available. That new development was certainly of the utmost importance, and he understood that a method employing photo-electric cells for speed determination was in course of development in Western Germany, for a new yard at Cologne, and by radar technique on the Southern Railway of the United States.

Mr Kubale raised the question of a fourth wagon in Figs 9, Plate 1. The Author felt that that was taking the case of the exception to the exceptional case. For shunting on that very abnormal basis, that was, into two adjacent sidings only, there would be no necessity for a hump yard.

However, on reflection, the Author would ask Mr Kubale to observe that an unlimited number of slow-running wagons could be humped into adjacent lines, after the three examples shown in Figs 9, Plate 1, without trouble. Furthermore, good runners could be intentionally converted into bad runners by appropriate brake applications.

Mr Shipp's comments about tires on hydraulic retarders were probably right; there was certainly a noticeable amount of very fine swarf deposited near the brakes.

The Author was obliged to Mr Dunbar for his lucid and authoritative remarks, and was glad to learn that an operating superintendent felt the necessity to call in a civil engineer in the design of a marshalling yard, to effect sorting of wagons. He reminded Mr Dunbar that Dr Johnson, in his dictionary, had defined " sorting " as " restoring order out of chaos." A civil engineer was, indeed, the right choice for that purpose, together with the signal and telecommunications engineer, and mechanical and electrical engineer. An estate surveyor was also sometimes useful.

The paradoxes referred to by Mr Moss were essential to produce the requisite wagon spacing which the signal department decreed as a *sine qua*

non for the proper operation of their automatic apparatus. It was quite a logical way of achieving that.

Mr Alley's remarks were of interest. However long-lasting the hook-and-chain brake might be, it possessed one serious disadvantage in that it could not be released easily and quickly. The Edge Hill brake was essentially a " run-away " brake.

The justification for secondary brakes, referred to by Mr McIlmoyle, was mentioned in Appendix 4, where it was made clear, in general terms, that secondary retarders were not suggested as a matter of course.

Mr Marchand's written contribution was very informative, particularly in respect of the resultant effects of good yards upon traffic generally. The Author was surprised to learn that the American centre automatic coupling was credited with being able to sustain a higher contact speed than the twin buffers fitted to European stock.

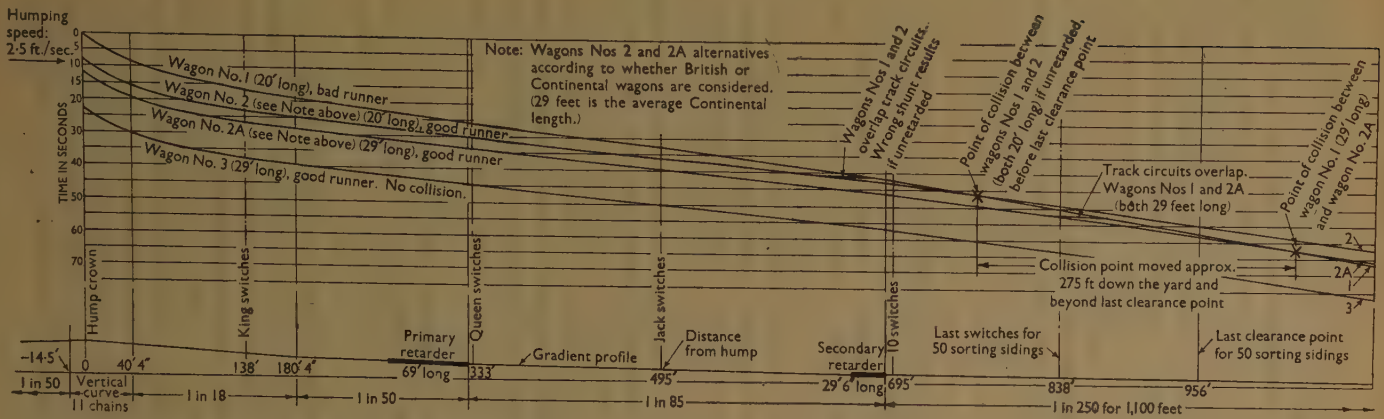
It was significant that Mr Marchand did not support the arrangement of tandem retarders. (The Author had not, so far, been presented with a detailed supporting statement, including calculations on the lines of the Paper, against the use of secondary retarders in the larger yards. That observation also applied to some members of the operating department in British Railways.) Mr Marchand's remarks about the simultaneous operation of retarders were considered pessimistic. The total number of wagons proposed to be dealt with per unit of time in the British yards, as compared with the French yards, was as 1·45 : 1, on account of the shorter stock generally in use in Great Britain. However, as explained in the Author's reply to Mr Moss, one brake operator would be given six levers to work, in the proposed design, as against twelve in some installations in France. But with those six levers only half the yard would be served. Assuming a relatively even distribution of wagons into the sorting sidings, the British operator would be called upon to deal with about three-quarters of the number of wagons offered in France. Putting it another way, the British proposal would offer three brake-sections to 75 per cent of the number of wagons passing through a two-brake-section French installation. The possible brake manipulations, being as 2·25 : 2, fortuitous rest gaps in the former arrangement should not be overlooked.

Figs 14 illustrated why, in certain circumstances, it was not possible to compare British with Continental practice. Being unaware of the precise friction values of Continental stock, the Author illustrated his case with British coefficients. Nevertheless, they were suitable for demonstration and, in fact, resulted in an under-representation of the exercise.

Correspondence

Mr H. C. Johnson observed that there seemed to be an inference in one paragraph of the Paper that small yards should be abolished in favour of large mechanized units. Certainly there should be, under

Figs 14


Humping speed: 2·5 ft./sec.
TIME IN SECONDS
0
5
10
15
20
30
40
50
60
70
Wagon No. 1 (20′ long), bad runner
Wagon No. 2 (see Note above) (20′ long), good runner
Wagon No. 2A (see Note above) (29′ long), good runner
Wagon No. 3 (29′ long), good runner. No collision.
Note: Wagons Nos 2 and 2A alternatives according to whether British or Continental wagons are considered. (29 feet is the average Continental length.)
Wagons Nos 1 and 2 overlap track circuits. Wrong shunt results if unretarded
Point of collision between wagons Nos 1 and 2 (both 20′ long) if unretarded, before last clearance point
Track circuits overlap. Wagons Nos 1 and 2A (both 29 feet long)
Point of collision between wagon No. 1 (29′ long) and wagon No. 2A
Collision point moved approx. 275 ft down the yard and beyond last clearance point
Hump crown
King switches
Queen switches
Jack switches
10 switches
Primary retarder
69′ long
Secondary retarder
29′ 6″ long
Gradient profile
Distance from hump
Last switches for 50 sorting sidings
Last clearance point for 50 sorting sidings
−14·5′
0
40′ 4″
138′
180′ 4″
333′
495′
695′
838′
956′
1 in 50
Vertical curve 11 chains
1 in 18
1 in 50
1 in 85
1 in 250 for 1,100 feet

TIME/DISTANCE CURVES SHOWING RELATIONSHIP BETWEEN COLLISION POINTS OF UNRETARDED WAGONS OF AVERAGE BRITISH LENGTHS AND OF AVERAGE CONTINENTAL LENGTHS, ASSUMING ROUTING INTO ADJACENT SIDINGS

nationalization, even greater scope for the installation of the large yard to assist in the development of a greater degree of inter-Regional working. On the other hand, the lay-out of British railways was such that there would still be a need for a considerable number of small yards, but they in turn required modernization which would procure substantial economy. There had been evidence between the wars that Germany had developed the small yard with a good deal of benefit to operation.

In any case care should be taken that heavy expenditure on any type of new yard was not undertaken until all the possibilities of through working by the adoption of block loading and other means had been exhausted. The first aim should be to avoid yards and close them.

It should also be borne in mind that too great a degree of centralization could involve unremunerative cross-haulage which was an expensive business.

The Author favoured the installation of both primary and secondary retarders, but Mr Johnson was not yet convinced that more than one set of retarders were required. Whatever arrangement of retarders was adopted the all-important point was the speed at which wagons passed into the sorting sidings from the retarder. There was evidence to show that in the French yards that speed could be admirably controlled and earlier retardation at primary retarders was unnecessary. The problem of overtaking was recognized, but the Author's figures indicated that there was a fairly wide margin of humping speed because the Author claimed that at 2·5 feet per second it was possible to shunt 6,500 wagons in 24 hours, a total much greater than was required in any yard yet contemplated. It was not without significance that the French, who had studied that problem closely and constructed a considerable number of new yards, had not thought fit to install secondary retarders. It should be admitted, however, that their wagons differed considerably from those in Great Britain; they were longer and also more consistent in their running qualities.

Probably the right approach to the problem was to experiment with both systems in the knowledge that with one type of brake, at any rate, subsequent adjustment should not prove to be either a difficult or an expensive matter.

Mr Johnson entirely agreed that the employment of one brakesman to every three or four sidings in the French yards was very extravagant. On the other hand, he doubted whether the employment of one brakesman in a large group of sorting sidings would be sufficient to reduce damage to the proportion stated, even when primary and secondary retarders were installed. He thought a more important point was the number of retarders in relation to the number of sorting sidings. One in about ten, which was roughly the proportion in the Toton and Whitemoor Up yards, was not sufficient; one in six, as at Achères, seemed to be about right.

The Author had rightly referred to the heavy cost of pushing-down

wagons in sorting sidings and to the consequent importance of eliminating that to the greatest possible extent. In Mr Johnson's view that would depend as much upon adequate and regular clearance of the sorting sidings as it would upon braking and gradients and he was inclined to think that the Author's suggestion that certain sidings should be 25 per cent longer than the normal train length was hardly sufficient. Where possible it would be well to aim at about 50 per cent, and so ensure continuous free movement of wagons well beyond the clearance points.

Relating that to the problem of primary and secondary retarders, Mr Johnson believed that the additional length in the sorting sidings was to be preferred to the additional length required for the installation of primary and secondary retarders.

Mr J. G. F. Inglis, writing from Pennsylvania, observed that the use of more than one set of retarders in the United States was primarily to give the operator a more delicate control, and to economize in the length of retarder provided by concentrating it before the tracks diverged. There was comparatively little interference between successive cuts on the main hump gradients owing to more uniform running and less overall friction, the main factor was, however, that the standard American boxcar was twice the length of the standard British wagon. The main purpose of primary retarders in British yards would be to regulate the spacing of wagons arriving at the secondary retarders where, in turn, the speed of entry into the sorting sidings would be regulated. He could see little theoretical or practical justification for the provision of three sets of retarders with manual control.

An all-electric retarder was now in use in America which was very similar to the electro-pneumatic retarder described by the Author. It was worked by an electric motor, through a system of gears, was quick acting, and was said to be simpler and cheaper to install and maintain than the electro-pneumatic type; it could also be divided into two or more independently acting sections. The degree of retardation was controlled by adjusting the tension in springs, instead of by air pressure as used in the electro-pneumatic type. The all-electric retarders had been installed on the Southern Railway system at the Ernest Norris Yard, Birmingham, Alabama, and at the John Sevier Yard, Knoxville, Tennessee.

Height compensation for total curvature in the sorting sidings, and allowance for resistance in turnouts were provided in some American yards, and Mr Inglis had been favourably impressed with an example of that in California. The difference in height involved was small since the outside tracks were always the most curved and therefore the lowest; that compensation could be used to provide cross-drainage. Self-guarded "frogs" —cast manganese crossings with raised flanges—bearing on the outside of the wheel, were normally used in American yards, and those gave more uniform running throughout turnouts. Switch-point protectors were also used in some places to keep the wheel flanges from hitting the points of

turnouts on sharp curves; they also helped towards uniform running, although for both it was essential that all wheel-tread widths should be the same. He expected that in British yards the amount of curve compensation required would have to be determined experimentally since it probably varied with the radius of curvature and the length of wheelbase for rigid-framed British wagons. In one American yard, near Pittsburgh, Pennsylvania, at present being rebuilt, all rails in the sorting sidings were to be welded into continuous lengths from end to end. The benefits of that in reduced maintenance, the provision of additional smoothness, and uniformity should be considerable.

One important problem which was at present receiving much attention in America, was that of siding gradient. There did not seem to be any disagreement that the exit end should be on a rising gradient to prevent wagons running beyond end clearance-point and fouling the switching leads to the departure yard. In Mr Inglis's view the gradient in the main body of the tracks should be such as to prevent a good runner, under good weather conditions, from accelerating to an excessive speed by the time it reached wagons already in the sidings. That would mean that such wagons would have to be released from the secondary retarders at a lower-than-buffing speed, whilst slower wagons would be released at faster-than-buffing speeds since they would tend to decelerate in the body tracks. To avoid interference between retarded and entry clearance point the lower the secondary retarders were placed the better. He agreed with the Author that the secondary retarders should be on a slight gradient to enable accidentally or deliberately stopped wagons to restart when released. In America the " equilibrium grade " for sorting sidings was between 1 in 500 and 1 in 600, and the maximum desirable buffing speed was taken as 4 miles per hour. In Great Britain the corresponding gradient would appear, from *Fig. 12*, to be about 1 in 300.

Where two sets of retarders were used, it was customary for the same man to operate both, as advocated by the Author. Having watched that control, however, especially where the primary retarder was used to regulate spacing, Mr Inglis thought that the man at the hump could control it, since the operators of the secondary retarders might well have one or more cuts to control when the primary retarder demanded attention. That might be simplified when using only one primary retarder by having it pre-set for heavy, medium, light, or nil retardation. In many American yards the actual gross weight of each wagon was recorded on the cut-list, and that would greatly simplify such a setting if performed manually. Retarders were also in use in which the degree of retardation was automatically adjusted to the gross weight by the wheel depressing a spring-loaded plate. As the Author's results show, however, the relation between gross weight and running characteristics were not constant because of journal conditions, etc. Therefore, whilst the weight-controlled retarder would probably serve for primary retardation, some form of speed or acceleration control

would be desirable in secondary retardation. Mr Inglis was of the opinion that the total retardation should be sufficient for the complete arresting of any wagon, or cut of wagons, in the primary retarder or the combined primary and secondary retarders, allowing a safety factor of about 10 per cent, although that might prove to be available in the retarder design factor. The total height of the hump should not be greater than would be required to permit the worst running wagon, under the worst weather conditions, to reach the far end of any sorting siding. Clearly it was advantageous to incorporate as great a percentage as possible of that retardation in each of the one or two primary retarders rather than in eight or more secondary retarders, and therefore the farther below the crown of the hump the primary retarders were placed the better. That placing, however, should be linked to the amount of catch-up between the fastest and slowest runners, both under the worst weather conditions ; to maintain this catch-up at the minimum, a sharp crown and steep initial gradient were beneficial. Mr Inglis knew of one European yard designed for an initial gradient of 1 in 15. To achieve those conditions, however, it would probably be necessary to prohibit the use of steam locomotives.

Unless the sorting sidings were also used in lieu of departure sidings, it would seem that their length should be limited to that into which all types of wagons could be humped in a controlled manner ; at present that would appear to be about fifty wagons. If that length were to be increased the proportion of rough shunts resulting in damage to wagon or its contents either immediate or cumulative, seemed bound to be aggravated. However, by application of more scientific methods than were at present in use, it might be possible to increase the lengths of the sorting-sidings. For such methods to succeed, either (*a*) controlled-speed-release secondary retarders would have to be interlocked with acceleration meters at a point about the retarders, so giving a measure of the running of each wagon ; or (*b*) in the case of only one set of retarders, velocity would serve to reflect the loss of energy through friction, etc. per unit weight of the wagon from the separation point (assumed constant) just below the crown. In both cases a further control, adjusted by track circuits, to the number of wagons already in the particular sorting siding, would be required. Such a yard could be worked without retarder operators, but the economies of construction and maintenance plus the provision of standby controls and operators might well defeat the idea.

The Author, in reply, agreed with Mr Johnson that a number of small yards would have to remain in any major reorganization, and the gist of his Paper did not intend to convey that that would not be the case.

Nevertheless, of those remaining, some economies could be effected by modernization and correct spacing of turnouts. Further, simple mechanical ground frames should replace scattered hand point levers.

The Author noted Mr Johnson's remarks about secondary retarders

but was glad to see that he favoured an experiment; the Author had no doubt about the outcome.

The prime difference between British and French yard problems, apart from wagon running qualities, was illustrated in *Figs 14.*

There was a practical difficulty in making sorting sidings of great length, and at the same time, obtaining a performance set out in the Paper. It was better to have multiplicity of tracks for one destination, than to attempt such long sidings as those suggested by Mr Johnson. The additional length required for the secondary retarders was put to the very best use.

Mr Inglis's remarks were of particular interest to the Author, as he had not been able to observe the working of American yards on the ground.

The mention of the all-electric retarders was very interesting, and also the comments upon cross-gradients and self-guarded "frogs." Mr Inglis was well qualified to speak on the two latter points, for he had taken part in the Whitemoor tests and, therefore, could assess the advantages with exactitude.

The speed of release at the secondary retarders could, for all practical purposes, be taken (in Great Britain) as ranging between 5 and 11 feet per second into a siding to hold about seventy-five wagons. Since the running characteristics and gross wagon weight were responsible for that difference of 6 feet per second, the automatic weigher on the approach to the hump, as mentioned by Mr Inglis, would be of value, because it would eliminate one remaining uncertainty, particularly in the case of covered wagons. The weigher would be a distinct advantage, whether or not automatic speed control was provided.

Track circuits, to indicate the spare capacity in the sorting sidings, would be an excellent thing, particularly in foggy weather. The economics of such a scheme might probably weigh against such a course, but if about six thousand 21-foot-long wagons could be regularly passed over one hump each day, then the position was likely to be quite different. The Author hoped that an opportunity would soon arise which would permit such a bold design to be put into execution.

Correspondence on the foregoing Paper is now closed and no further contributions will be accepted.—Sec. I.C.E.

MARITIME AND WATERWAYS ENGINEERING DIVISION MEETING

14 May, 1953

Lieut.-Col. R. H. Edwards, Member, Chairman of the Division, in the Chair

A Lecture entitled "**Echo Sounding in Modern Coastal and Harbour Survey**" was delivered by Commander D. H. Macmillan, R.N.R., F.R.I.C.S., and, on the motion of the Chairman, the thanks of the Division were accorded to the Lecturer.

The following is an abstract of the Lecture.

The ancient Mediterranean seamen venturing beyond the Pillars of Hercules laid the foundation of those hydrographic arts that fell into corruption with the rise of Rome. But the Renaissance and Reformation marked the death knell of African and Latin sea power, and the rise of the exploits of Drake.

The birth of no less than three great British dominions was assisted by use of the ancient lead and line in the hands of the intrepid Cook.

Upon such a foundation the great names of the Hydrographers of the Royal Navy mark the milestones of Britain's progress in charting the world and developing those fundamental principles of marine survey which must form the framework within which we should necessarily use the more refined techniques now made available by modern science.

The name of Lieut. Murdoch Mackenzie, R.N., bulks large in the early 18th century hydrographic surveys round the British coasts. He was fortunate enough to live at a time when the vernier, Hadley's octant, and the theodolite were increasing in precision, and the necessary sound trigonometrical land control was becoming available to the practised small-boat seamen, skilled in the use of sextant fixing afloat by angle and transit, or double simultaneous angles taken by two officers with the necessary sea legs. The three-legged protractor, or station pointer, became a necessary development along these lines.

British Admiralty practice, the foundation of all sound boat survey work, has since those times necessarily proceeded along the lines of resection by double simultaneous sextant angles, using the properties of the circle to control the pattern of lines from the survey ship.

The advance of iron shipbuilding and steam navigation has proceeded apace since the middle of the 19th century, but it was only towards the end of that century that the draught of ships exceeded the 21-foot maximum-load draught of the great steel sailing clipper ships. Even now, apart from the 1,000-foot liners, this rarely exceeds 30 feet.

Consequently, up to the first decade of the 20th century, the need for hydrographic detail in the coastal approaches from the deep water into the terminal estuaries was generally felt only to extend offshore to the 5-fathom contour.

At the present day the need for close detail reaches out to the 10-fathom contour in consideration of the rolling of heavy-draught liners drawing 7 fathoms, and the possible increase of draught by bilging owing to collisions in fog, casualties in war, etc., and the requirement for safe anchorage at low-water times.

It has therefore become necessary to extend good trigonometrical framework to cover the more remote coastal approaches to harbour and estuarine termini, to enable the seaman to plan and execute closely planned lines of soundings, not only for sounding-out approach channels leading inwards from the deep offshore contours, but also to control the design and dredging of straight channel margins, suitably aligned to dominant tidal streams, as well as ample artificial curves with radii well within the reasonable turning helm limits of the largest liners in shoal waters, without forcing them to resort to emergency control by engine movements.

Furthermore, it is now becoming necessary to design channels to prepare for radar control of ships' tracks in times of poor visibility when electronic research proceeds further along the inevitable lines of progress.

Soundings in a tide-way by lead and line cannot achieve the necessary efficiency in speed or accuracy, and favourable fine-weather periods, with good sea-surface, are accordingly wasted unless we have at our disposal rapid and accurate techniques that will not let us down.

In the Lecturer's experience it is quite impossible to get an accuracy within 6 inches by lead and line under such circumstances, owing to catenary error, even on a hard bottom. If dredging quantities in situ are made the basis for costing contracts, the ancient device is quite inadequate for safeguarding a major harbour authority, either in the preparation, or execution, of such contract.

During World War I the use of subaqueous sound-ranging for the horizontal location of ships preceded the development of echo sounding, which uses reflected sound pulses transmitted vertically below a ship, the interval between transmission and reflexion being recorded graphically on some form of paper record.

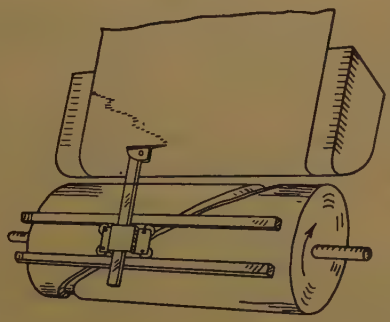
The linear scale used for recording is, of course, related to stylus speed which, to give equal scale (1 foot = 1 foot) must move at half the speed of sound in water, or approximately 2,400 feet per second.

The original deep-water method was by means of hammer transmitter and stop watch, but the intervals required for accuracy in shoal water could not be dealt with by such rudimentary devices, and the mechanical recorders have subsequently been devised to achieve stylus speeds necessary for the largest scales required :—

(1) The " scroll spiral " method using an oscillating stylus (see *Fig. 1*).
(2) The radial-arm " Challenger " method patented by the British Admiralty.
(3) The continuous-band method.

It is obvious that (1), involving discontinuous and reversing motion, must have serious mechanical limitations at high speed, as well as rendering impossible the very desirable requirement for a uniform stylus speed.

Fig. 1.



Scroll-Spiral Actuator of Stylus

At high speed (3) has obvious mechanical difficulties owing to the " nip " over the sprocket wheel, although in this case a uniform and unidirectional stylus speed is rendered possible.

It is very clear that the second mechanical method provides the solution adopted in the physical universe by diverting straight-line motion to uniform motion on the circumference of a circle.

The M.S. X instrument (Kelvin & Hughes) at its highest speed gives a scale of $\frac{1}{8}$ inch to 1 foot of depth, thus enabling depth to be measured to an accuracy of $\pm$ 3 inches; the more modern M.S. XXI instrument gives a scale of about $\frac{1}{10}$ inch to 1 foot.

The Lecturer prefers the earlier instrument for three reasons :—

The large vertical recording scale.

The lower stylus speed of 300 against 533 revolutions per minute.

The larger radius of stylus and consequently flatter arc.

It is now necessary to say that if an echo-sounding equipment is employed in costal areas *without* resorting to adequate and careful calibration and proper timing adjustment, and if the economic speeds of survey, now made possible by sextant graph techniques, are not developed, the immense advantages now made available by echo sounding will be utterly wasted, and the method will suffer quite unjustifiable abuse or lack of confidence.

Graphs and tables have been prepared (based on H.D. 282) enabling

stylus speed for mean specific gravity and water temperature on the site to be pre-set on the instrument. Reflector bar-check (as is shown in the film) can test performance very precisely, thus giving a double check relating accuracy directly to fundamental linear steel-tape standards.

If these simple precautions are neglected, nothing but chaos and inconsistency can result, but if they are taken and tachometer checks are made and recorded during survey, accuracy to $\pm$ 3 inches is a proven possibility.

Figs 2

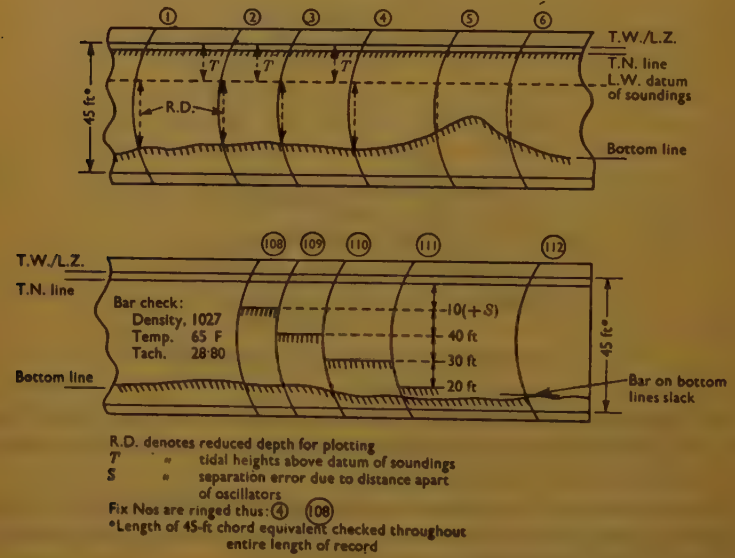


Diagram of Echo-Sounding Record (taken by M.S. XXI Recording), with Annotations for Sounding and Bar Check, showing Method of Accelerating E/S Record

It is therefore essential, when sounding, to adjust speed for specific gravity and temperature at mean depth before and after survey, checking and recording consistency of speed performance throughout the work. Each echo-sounding record will therefore bear its own criteria for scale, consistency, and zero calibration (see *Figs 2*), and continuous tidal readings at close representative visual gauges can be plotted below the true water-line zero to enable soundings to be read off directly and accurately for plotting. In estuarine work, the Lecturer considers this to be essential, although the record operator when afloat should read off and call soundings at, say, 10-second intervals, for conning and general logging in the sounding book throughout the survey.

It is very important to ensure that visual tide gauges of reference are representative and that Bernoulli effect is avoided.

In Southampton Water, for example, the stationing of visual tide gauges for Contract is planned for a maximum limit of 1 mile from any sounding point, and critical areas in narrow channels, with shoal margins, are not sounded when tidal streams exceed ½ knot. Differences of nearly 1 foot have been experienced when reducing on the same near-shore tide gauge after sounding with small and large tidal stream values, respectively.

Apart from this precaution, based on special circumstances, there is no reason why sounding in open estuaries cannot be carried out with fairly strong tidal streams, although it is essential to run a few slack-water test lines to check the work.

Work done in preparation for the recent Southampton—Calshot major contract gave close correspondence between daily overlaps on the collector tracings inked-in in different colours, and when sustained discrepancies of 6 inches occurred, re-surveys were always ordered. The Lecturer does not recollect this happening more than twice, and reconciliation to ± 3 inches was demonstrated as actually possible.

The coverage of the Southampton area by sextant graphs has proved most profitable and expeditious in every way.

There would always be occasions when resort must be had to the older and more tangible methods. There are instances when silt clouds and other phenomena obscure the real bottom, and in any case the echo cannot indicate whether a reflexion is off metallic material or that common to the natural bed.

A cast of the lead and its " feel " in such conditions is of the greatest value, and if a sharp spike is fitted below a heavy 28 lb. flat-based lead, a good idea of the sub-surface can sometimes be obtained. In any case the art of sweeping channels for obstructions using, if possible, tidal streams, must always be used to clear a fairway, especially when alterations in channel margins expose ancient wrecks which may conceivably be missed even by echo sounding.

Also, the alteration from " pong " to " ping," now coming into commercial application, is very valuable in picking out obstructions on a flat bottom. Not even this method, however, is likely to obviate requirement for sweeping in the present state of our knowledge, and its importance is therefore stressed.

[At this point, the Lecturer showed a film illustrating the procedure of echo sounding.]

Control of Areas within Sight, but Remote from Coasts

Suitably sited and conspicuous shore marks can often give very precise control of remote bars by the construction of equiangular arc-graphs compiled by machine. Provided the angle of intersecting of the two arcs is more than 50 degrees, and linear sensitivity to angular change is adequate, a closely spaced pattern of sounding lines can be run under reasonable

nautical conditions, and repeated examinations to determine buoyage and necessary dredging are capable of efficient control.

Hyperbolic Navigation

Hyperbolic navigation now comes to the assistance of the offshore surveyor, and provided scales are larger than 1/40,000 the practical accuracy to within $\pm$ 30 yards will give valuable control in covering remote approaches to termini. This facility is not yet precise enough for harbour charts and plan scales increasing from 1/25,000 to 1/5,000 but no doubt the next decade will see a great increase in the order of accuracy available by such electronic methods.

Finally, the Lecturer would stress the importance of placing new nautical and hydrographic survey devices within the context of proven ship-control techniques developed in the charting of the world by the hard experience of seamen, and in particular the British Admiralty, to whose Hydrographers seamen and engineers have contracted an eternal debt.

CORRESPONDENCE

on a Paper published in Proceedings, Part II, February 1953

Paper No. 5897

"Post-war Coast Protection Works along the South-East Coast of England, which have been Undertaken by the Kent River Board as Part of their Functions in Connexion with Land Drainage" †

by

George Cubley Crowther, O.B.E.

Correspondence

Mr Jack Duvivier congratulated the Author on his originality and enterprise in breaking away from the traditional earth bank with a protected face, when promoting a scheme for the protection of the low land between Reculver and Birchington.

The estimated cost mentioned by the Author worked out at approximately £19 per foot run, which was very reasonable in view of the high standard of protection afforded by the work, and the increased freeboard obtained over what had been there previously.

Incidentally, would the Author explain what he had meant on p. 202 by "12 feet above mean high-tide level"? The level of mean high-water of spring tides at Reculver was approximately 7 feet above Newlyn Datum, so that a crest level of 21·00 O.D. would be 14 feet above M.H.W.S. and rather more above the mean of high-water spring and neap tides.

Mr Duvivier understood that the length of wall which had been completed by the end of January 1953 had withstood the abnormal storm surge on the 1st February with complete success in contrast with the clay banks on either side, which had been overtopped and badly breached.

The question of dead weight was an important consideration in the design of many of the Thames-side sea walls. At some places the marsh land on which the banks had been originally constructed had a very low bearing capacity, and there was a certain amount of risk involved in heightening an existing earth bank by depositing further clay on the top and side slopes.

† Proc. Instn Civ. Engrs, Part II, vol. 2, p. 196 (Feb. 1953).

Mr Duvivier noted that both at Reculver and Dymchurch the Author had paved the aprons with pre-cast blocks. Since it was appreciably cheaper to lay a 6-inch thickness of in-situ concrete than a 6-inch thickness of precast concrete, he concluded that the Author had been afraid that a differential settlement might occur in the underlying filling, which might lead to the destruction of a rigid slab.

Although Mr Duvivier doubted whether the relative movement between one part of the bank and another would be sufficient to necessitate the adoption of a flexible apron consisting of small precast units, there was no special difficulty in obtaining a reasonable measure of flexibility in a cast-in-situ concrete apron. It was only necessary to divide the apron into a sufficient number of sections by means of transverse and longitudinal joints. The thicker the apron the wider apart would be the joints. If settlement occurred the joints would, of course, have to be pointed with a mastic compound from time to time, but the same thing applied in the case of aprons of precast units, except that there were more joints to maintain—and joints were always a potential source of weakness in a sea wall.

Possibly the Author was dubious about the sort of concrete which could be obtained by in-situ deposit between tides, but there was no need for apprehension on that score either, provided the Engineer specified his requirements with precision and the work was properly supervised. The essential requirements to be observed in casting an in-situ apron, apart from the obvious requirements that the mix should be properly designed and well graded, and the concrete thoroughly consolidated after being placed in position, were that the work should be organized in such a way as to ensure that the concrete had taken up its initial set before the flood tide covered it, and that it should have acquired sufficient early strength to withstand wave action without undue abrasion, should rough seas be experienced.

Obviously, there were certain weather conditions under which concreting between tides at a low level should not be attempted or resumed until more favourable conditions were forecast. Such conditions were most frequently encountered during the winter, and it was therefore advisable to do as much of the low level work as possible during the summer and concentrate on the superstructure, or other less vulnerable work, during the winter.

The Author, in reply, observed that Mr Duvivier, in his remarks on the Northern Sea Wall, had asked for an explanation of the term " 12 feet above mean high-tide level," and had rightly pointed out that, at Reculver, " high water at spring tides " was given as approximately 7 feet above Newlyn Datum. The crest of the wall designed by the Author would therefore be 14 feet above the latter level.

The Author pointed out that from a series of observations taken during the past 20 years, he had found that it was reasonable to expect a high

tide at Reculver, without any influence of surge or local storm, of 9 feet above Newlyn Datum, several times each year ; he had therefore used his experience in that connexion as a basis for the 12-foot margin. He was convinced that that margin was a reasonable one for that length of wall, and that if the scheme as designed had been completed before the recent high tide and surge there would have been little damage on that length of coast.

With regard to Mr Duvivier's second point, concerning the advisability of providing a facing of precast interlocking blocks, the Author stated that he was still in favour of heavy interlocking precast blocks rather than larger facings cast in situ. Settlement even in reasonably-sized local areas was very varied and unless the facing was very substantial it would break up under the stress of storm conditions and might even do so under its own weight if not heavily reinforced ; that was especially pronounced where the underlying strata contained beach and shingle. Mr Duvivier had also to some extent answered his own question when he admitted the necessity of extreme care in the control of placing and mixing in-situ concrete, but the Author did not think that he (Mr Duvivier) had given sufficient prominence to the extreme difficulty of carrying concrete work and of placing in cases where the period of low tide, when the work would not be submerged, was short. Even if the work was carefully planned to be undertaken at low neap tide it was very hard to predict that some abnormal condition would not prevail, so often the tidal conditions as forecast were unreliable. Of course, a cofferdam could be provided for each length as undertaken, but where miles of sea walls were to be constructed, as had often been the case in his experience, the expense was prohibitive.

CORRESPONDENCE

on Papers published in
Proceedings, Part II, June 1953

Railway Paper No. 48

" The Design of Structures in Relation to Maintenance and Inspection " †

by

Frank Turton and Norman Stewart Cox, B.Sc.(Eng.), M.I.C.E.

Correspondence

Mr W. T. Wilks observed that the Authors appeared to have overlooked the fact that there was still, in Britain, a shortage of steel and building materials, and evidently disregarded the recommendations contained in memoranda issued by the Ministry of Works. Since the British Railways were such large users of steel and other building materials, there was every reason why they should strictly observe those recommendations so as to make their contribution in the economy drive. Furthermore, the saving in the use of those materials would automatically result in some economy in the present-day working of the railways—now a matter of urgency.

Mr Turton had stressed the confidence he placed in the reliability of the properties of steel, and appreciated the efforts made by the steel industry in providing such first-class material. Although the railways in Britain had been large users of steel for many years, it would be interesting to know what contributions they had made in the past towards any research in the manufacture and improvement of the quality of steel.

In the past 40 or 50 years, British railway engineers had had a poor record for research work ; in fact, it had been difficult even to induce them to accept new methods tested and tried by enterprising companies. It was hoped that in the field of research of prestressed concrete, they would make their fair contribution and, in fact, endeavour to become leaders, since their resources were greater than those of any other industry and certainly their use of prestressed concrete was far more extensive.

It was, however, encouraging to note that, in the past 5 or 6 years, some railway structural engineers responsible for policy-making were considering the use of prestressed concrete as a medium, for as recently as

† Proc. Instn Civ. Engrs, Part II, vol. 2, p. 365 (June 1953).

1946, one railway structural engineer's view of it had been, to quote, " We don't want anything to do with piano wire."

Mr Cox had pointed out difficulties in design and materials, but offered little help towards their solution. The experienced designers had been fully aware of those difficulties in what was the Great Western—and later the Western Region—for the past 25 years but had always been discouraged from putting forward suggestions to rectify them. The proposal contained in the Author's conclusion on p. 393 would not solve the many problems. It was true, however, that an exchange of views between the design and maintenance staffs would be helpful in some small measure, but the real solution would be for selected members of each section to spend several years in each of the other sections. So far as the Western Region was concerned, the latter suggestion had always been vetoed and, consequently, there had been little progress in overcoming the many maintenance problems presented by Mr Cox. During the existence of the old Great Western Railway, it had been the procedure for the design section to prepare designs, estimates, and contract documents and submit them to the District Engineer for comments but, invariably, any criticism offered usually made manifest the lack of interest in, and knowledge of, the designer's work.

Fig. 19 showed one expensive type of smoke chute which had been recently devised, using asbestos-cement sheets. Was it definitely known what would be the effects of smoke on that material, and could any indication be given of the life of the chute ? It should be apparent to any engineer that, considering the amount of smoke drifting about locomotive sheds, a smoke chute was totally inadequate to deal with the situation. It was suggested that the only effective way of dealing with the problem was to have mechanical extraction.

Referring to *Fig. 16*, the type of structure which was being used for a new locomotive shed on the Western Region was incompatible with the knowledge railway engineers had of the detrimental effects of smoke fumes on steel. Braced roof trusses and lattice roof-girders should have been the last choice for that particular job, and when the cost of maintenance was also taken into consideration, it was very uneconomical. If the roof lay-out had to be northlight construction (a point which was difficult to concede) then obviously the roof girders should have been of the Vierendeel welded type and the rafters of the trusses should have consisted of rolled steel channels or joists only so as to eliminate the use of light structural bracings and pockets in which corrosion was rapid. Capital expenditure might have been slightly higher but the maintenance cost would have been reduced.

The deterioration of the reinforced-concrete structure illustrated in *Fig. 8* was not surprising when it was realized that on the Western Region there was little appreciation of the value of quality control of concrete even so late as 1939, although from about 1910 onwards, British civil

engineers had been taking an interest in reinforced concrete and had carried out much research work on that important point by 1939. On the Western Region, the design of the first reinforced-concrete structure by the Railway's own civil engineering staff had not been undertaken until 1928–1929, and the first real attempt to formulate its own specification for concrete had not taken place until 1943 or 1944.

In *Figs 11*, attention was focused on a detail of construction for roof trusses, pointing out the weakness of having double-angle rafters and main ties. The defect had been well known for at least 25 years, but no solution had been found for large-span trusses that was satisfactory and economical. The experienced designer had, for many years, used single angles wherever possible in short-span trusses, but above 60 feet the idea of a single angle was invariably impractical and uneconomical. It was believed that the rigid frame construction might prove to be the answer.

A last point for comment was the size of the standard G.W.R. glazing bar. If a 3½-inch-deep bar was used for all spans of glazing, then for short spans it was an extravagant use of soft timber, a material which was very scarce.

The Authors, in reply, stated that, far from having overlooked the fact that there was still a shortage of steel and building materials, they were acutely aware of it, and indeed it was difficult to see how a responsible designer could be so ignorant of the situation as Mr Wilks seemed to suggest, because he had been forced to grapple with the many problems associated with shortage for the past 13 years.

Although some railways had been making extensive use of reinforced concrete before 1939, the subsequent shortage of steel and timber had led to more bridges being built in concrete on the late London, Midland and Scottish Railway and the present London and Midland Region than in steel—a complete reversal of policy, which had not only resulted in the saving of steel, but had also contributed in no small measure to the more economical working of the railways. It should also be pointed out that railway structural engineers had not only considered the use of prestressed concrete, but had been using it, particularly in bridge work, for the past 7 years. Their contributions towards the furtherance of the use of that medium had been recorded in several Papers and other publications.

Where it was necessary to use steel—and there were many cases of railway-bridge reconstruction work where there was no alternative—extensive use was made of welding with a consequent saving of up to 20 per cent in the weight of steel as compared with a riveted structure.

The right use of those two materials—concrete and steel—should be the railway engineer's constant endeavour, and that automatically resulted in true economy.

Mr Wilks had stated that the railways in Britain had been large users of steel for many years, and had asked what contributions they had made towards any research in the manufacture and improvement of the quality

of steel. There were several ways of contributing to research of that kind, and surely one of them was to be a large and discriminating buyer ; in that connexion it was interesting to recall that the former London and North-Western Railways had built its first steel bridge carrying the line in 1876, and from 1884 onwards that Company had almost ceased to use wrought iron for its structures. That was long before many other authorities and engineers had begun to use mild steel for similar purposes.

Mr Wilks had made several interesting comments on Part II of the Paper, but was not entirely up-to-date in his knowledge of Western Region practice.

His suggestion that selected designers should spend several years on works maintenance, and maintenance staff a similar period on design was counsel of perfection which could rarely be followed in practice.

The smoke chute shown in *Fig. 19* was a development of the old pattern timber chute and was proving less costly to maintain.

Mechanical extraction of smoke from engine sheds was more costly to install and maintain and was really effective only when engines were correctly placed in relation to the extractor fans.

Braced roof trusses and lattice roof girders in Western Region engine sheds had given satisfactory service without excessive corrosion because of their height above engine-stack level. An example of that could be seen in the Old Oak Common shed constructed before 1900.

Airport Paper No. 23

" Methods of Soil Stabilization and their Application to the Construction of Airfield Pavements " †

by

Donald John Maclean, B.Sc., and Peter John Mackenzie Robinson, B.Sc.(Eng.), A.M.I.C.E.

Correspondence

Mr R. S. Colquhoun referred to the Authors' suggestion, on p. 450, that for temporary military airfields it would be desirable to devise a surfacing which combined the rigidity of metal surfacing with the imperviousness of bituminized hessian surfacing. With that suggestion he completely agreed, but he was at variance with the Authors' opinion that such a development had yet to be made.

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† Proc. Instn Civ. Engrs, Part II, vol. 2, p. 447 (June 1953).

During 1944 a number of airfields had been built in Eastern Bengal and the Arakan, under the direction of the Engineer-in-Chief, India. Those airfields had been constructed with compacted soil bases and surfaced with a combination of prefabricated bituminous surfacing and pierced steel plank. At Dohazari, near Chittagong, the P.S.P. had been bedded into a 1½-inch bituminous sand carpet, laid on top of the P.B.S. On other sites, notably Agartala and Fenny, the P.S.P. had been laid directly on the P.B.S. The waterproof membrane had thus been completely ruined, since the sharp edges of the pierced sections of the plank had punched circular holes in the P.B.S. when subjected to load. That difficulty had been overcome by laying two layers of P.S.P., the lower layer being reversed so that the sharp edges pointed upwards. That method had been used at Petenga, in the Arakan, and subsequently in the initial stages of the rehabilitation of Kallang airfield, Singapore. A more striking instance of P.B.S./P.S.P. surfacing was its use on the temporary runway at Changi, Singapore, where the subsoil consisted of recent alluvium and mangrove swamp. That temporary runway had been in constant use for 3 years, 1946–49, by all types of aircraft, including Constellations. Though settlements of up to 10 inches had occurred, that site provided an example of the capacity and life of a " temporary " airfield equipped with P.B.S./P.S.P. surfacing.

The Authors had stated, on p. 450, that the general form of temporary military airfield was visualized as a stabilized soil base with a prefabricated surface. Under active service conditions in forward areas, the key factors in airfield construction were the amount of mechanical equipment available and the tonnage of material which had to be imported. Those two factors would largely determine the time which had to elapse before the site was operational. The techniques of soil-cement and soil-bitumen stabilization were known to both British and American military engineers serving in south-east Asia from 1943 onwards, but those techniques had never been used for forward airfield construction, nor did Mr Colquhoun know of any instance of those techniques being similarly employed in north-west Europe or in Korea. The reasons were not far to seek. All soil stabilization by admixture required a careful soil survey, specialized mixing plant, skilled supervision, and the delivery of large quantities of the stabilizing agent in a short space of time. The breakdown or absence of any one of those requirements would seriously jeopardize the rapid completion of any forward airfield. On the other hand, the grading and compaction of soil could be carried out with standard earth-moving equipment, and the subsequent surfacing of the soil base with P.B.S. and/or a metal surface were tasks which could be done by semi-skilled manual labour. It was not surprising, therefore, that those were the techniques used for forward airfield construction in south-east Asia and Korea.

In future, it was likely that the construction-time element would be even more important, whilst the longer and wider runways which were

now required would necessitate the selection of sites which were naturally flat and which were frequently ill-drained and of low bearing capacity. The development of such sites into forward airfields would, he suggested, be largely a matter of providing them with a composite surface which was impervious and which was capable of so spreading the load of aircraft wheels that that load, when transmitted to the subgrade, was within the range of the subgrade's natural bearing capacity. To avoid permanent distortion where local overloading occurred, such a surface should be under an initial prestress, which could later be increased should the role of the airfield be changed, involving its use by heavier aircraft. A modified form of channel track, which lent itself to prestressing, in combination with P.B.S. would go far to fulfill those requirements and might well eliminate the need for a stabilized base in forward-airfield construction.

The Authors, in reply, expressed a doubt as to whether, taking into consideration the higher tire pressures of modern aircraft, P.S.P. would prove as adequate a form of construction now as it had been during the 1939–45 war.

They found it difficult to believe that the construction of airfields by compaction of the soil could be carried out with less attention to detail than those constructed by the soil-cement process and yet give equally good results. It also seemed doubtful to them whether it could be carried out under such varying conditions of drainage and climate.

It was not generally realized, and did not seem to have been taken into account by Mr Colquhoun, that the quantities of materials which he considered prohibitive in the case of soil-cement stabilization were more than doubled for two layers of P.S.P. For instance, a soil-cement construction stabilized with 10 per cent of cement at a dry density of 110 lb. per square foot for a depth of 6 inches could carry as much traffic and give at least as great a length of service as P.S.P. In addition, it had to be remembered that there were other drawbacks to the use of metal surfacings in war-time, and taking all those into account, it was the Authors' opinion that their development should be regarded with caution.

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Mr W. Fillingham Brown (Member)
Mr R. le G. Hetherington (Member)
Mr Hugh G. Ramsay (Member)
Mr R. C. S. Walters (Member)

RAILWAY DIVISION

Chairman: Mr W. K. Wallace (Member)

Appointed by the Council

Mr F. E. Campion (Member)
Lieut.-Col. E. C. Cookson (Member)
Mr I. R. Frazer (Member)
Mr John Ratter (Member)
Mr M. G. R. Smith (Member)

Elected by the members

Mr A. H. Cantrell (Member)
Mr N. S. Cox (Member)
Mr J. R. Dallmeyer (Member)
Mr C. E. Dunton (Member)
Mr A. K. Terris (Member)

ROAD DIVISION

Chairman: Mr Arthur Floyd (Member)

Appointed by the Council

Dr W. H. Glanville (Member)
Mr R. R. W. Grigson (Assoc. Member)
Mr R. Nicholas (Member)
Mr E. J. Powell (Member)
Mr R. J. Samuel (Member)

Elected by the members

Lieut.-Col. G. T. Bennett (Member)
Mr B. F. J. Bradbeer (Assoc. Member)
Mr C. S. Chettoe (Member)
Col. Sydney Green (Assoc. Member)
Mr Stanley Mehew (Member)

STRUCTURAL AND BUILDING DIVISION

Chairman: Professor A. J. S. Pippard (Member)

Appointed by the Council

Dr H. Q. Golder (Assoc. Member)
Mr R. T. James (Member)
Mr E. O. Measor (Member)
Mr P. E. Sleight (Member)
Mr L. Scott White (Member)

Elected by the members

Mr Ralph Freeman (Member)
Mr H. J. B. Harding (Member)
Mr D. H. New (Member)
Mr Gilbert Roberts (Member)
Mr F. S. Snow (Member)

WORKS CONSTRUCTION DIVISION

Chairman: Mr A. C. Hartley (Member)

Appointed by the Council

Mr S. W. Cox (Member)
Mr E. M. Fitt (Member)
Mr H. J. B. Harding (Member)
Mr A. M. Holbein (Member)
Mr Joseph Rawlinson (Member)

Elected by the members

Mr V. F. Bartlett (Member)
Mr Jack Duvivier (Member)
Mr A. F. Haxton (Member)
Mr F. W. Sully (Member)
Mr R. M. Wynne-Edwards (Member)

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